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ABSTRACT

Designed for high school electronics students, this third document in a series of six electrical learning activity packages focuses on basic electronics. An introductory section gives the objective for the activities, an introduction, and an outline of the content. The remainder of the activity book is comprised of information sheets and job sheets on topics such as (1) the electron tube, (2) the triode tube, (3) use of a "B" battery, (4) transformers, and (5) solid state. Each job sheet follows a typical format that includes the objective, materials, explanation, procedure, and evaluation questions. (LRA)

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CONNECTICUT STATE DEPARTMENT OF EDUCATION
Division of Vocational Education
Hartford

ELECTRICAL EXPERIMENTS

VT - 214 - 12 - 3

PART III

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BASIC ELECTRONICS

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BASIC ELECTRONICS

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Information Sheet
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THE ELECTRON TUBE

Objectives:

To gain an understanding of the electron tube and its operation.

Introductory Information:

An electron tube is a device used in electronics for rectification, amplification, detection, etc. The basic principle is 'a cathode emits a stream of electrons which are attracted to a positive charge plate.'

Body of Information:

The free electrons in a metal are in a constant state of motion. As the temperature of the metal is raised, these free electrons speed up until, when the temperature is raised high enough, some electrons fly off into space. The action is somewhat similar to the evaporation of molecules of water as its temperature is raised reyond the boiling point and the vapor turns to steam. This boiling off of electrons is called thermionic emission, and is the starting point of the action of nearly all electron tubes.

The part of the tube that lets the electrons escape is known as the emitter or the cathode. Tubes that are used with high power, such as transmitting types, usually use a filament of tungsten which is heated by electric current until electrons are boiled off.

Tubes of lesser power and operating at a lower temperature, a filament of tungsten in which has been dissolved some thorium oxide are used. It is called a thoriated filament.

There are two types or methods used for heating the cathode of a tube. The directly heated method uses the cathode as a filament and directly heated by electric current, and, the indirectly heated which uses the separate filament to heat an independent cathode.

Diodes

In most electron tubes, the cathode and the emitter are sealed in a glass envelope and the air is removed. This vacuum serves two purposes: one, since there is no air in the tube, the filament cannot burn up, and two, since the air is removed there is no opposition to the movement of the electron by the electrons of the gasses that make up the air.

When the cathode is heated enough so that the electrons are boiled off, they form a cloud of electrons known as the space charge. This charge of electrons repel the electrons of the cathode and keep it from disintegrating.

If a positively charged electrode (called an anode or plate) is inserted in the tube, the electrons of the cloud nearest to this electrode are attracted to it. (LAW OF CHARGES - Like charges repel, unlike charges attract.) This reduces the space charge and allows more electrons to be emitted by the cathode.

The Electron Tube

A battery, known as the B battery, is placed in the plate circuit and negative terminal of the battery returns the electrons to the cathode.

The external circuit from plate to cathode is called the plate circuit, and the flow of electrons in this circuit is called the plate current. The internal flow of electrons from cathode to the plate is called the space current.

As the voltage on the plate is made larger and larger, more and more electrons of the space charge are removed. Thus more and more plate current flows. At a certain point, there is no space charge left, and so the electrons go directly to the plate and no extra voltage in the plate circuit can cause more electrons to flow at one time. This maximum plate current is called the saturation current.

The tube consisting of only a emitter and plate is called a diode tube (di means two and ode comes from electrode).

The diode illustrates the basic principle underlying all electron tubes. A cathode emits a stream of electrons which are attracted to a positively charged plate.

The anode of the ordinary receiver-type tube is usually made of nickel or iron. The electrons emitted by the cathode tend to heat up a plate upon striking it. For this reason the plate is made as large as possible to eliminate this heat energy which could cause poor operating characteristics of the tube.

If the electrons emitted by the cathode strike the plate too hard, electrons from the plate could be torn loose and repel other electrons coming from the cathode and cause the electron flow in the plate circuit to stop. This action of electrons being torn from the plate inside the tube is known as secondary emission.

The diode tube is used mostly as a rectifier tube. It changes the A.C. current in the plate circuit to a pulsating D.C. current. The reason for this is a diode only conducts when the plate is positive.

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BASIC ELECTRONICS

Job Sheet 1
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Vacuum Tubes - The Edison Effect

Purpose:

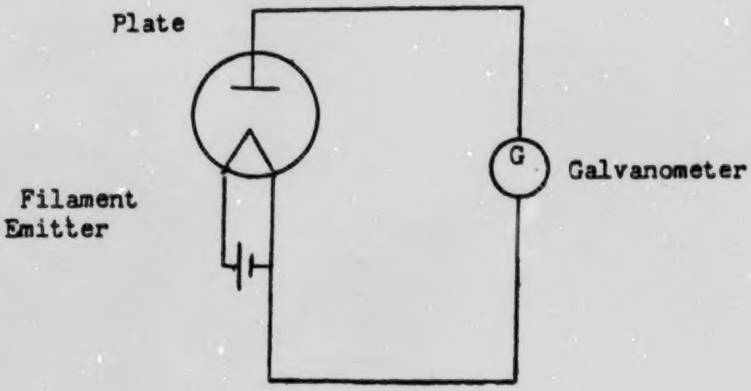
To discover the working principle of a vacuum tube.

Materials To Be Used:

Two-electrode tube; socket; galvanometer; battery; connecting wires; and a tube manual.

Information:

An electron tube is a one way valve in which electrons move from a cathode or emitter to an anode or plate. The plate must be positive with respect to the emitter. The tube works on the principle of unlike charges attracting and like charges repelling.



Procedure:

Connect circuit as shown in diagram. Locate pin numbers from tube manual.

Apply rated voltage to filament. Allow tube to warm up. Observe galvanometer action.

Reverse battery connections and again note galvanometer action.

Questions:

1. Describe fully what you observed while performing this experiment.
2. Does the galvanometer deflex with the battery connected in either direction? Explain fully.
3. What is the "Edison effect"?
4. Name the main parts of a two-element tube.
5. Explain how the diode tube acts as a rectifier.

References:

Gerrish: ELECTRICITY AND ELECTRONICS, Chapter 11

Johannsen & Journigan; BASIC ELECTRONICS, Page 8

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BASIC ELECTRONICS

Job Sheet 2
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The Two-Electrode Vacuum Tube

Purpose:

To discover what effect, if any, (1) varying the plate voltage and (2) varying the filament current have upon the plate current of a two-electrode tube.

Materials Used:

Two-electrode tube (if one is not available an ordinary three-electrode type 201-A tube can be used with its grid terminal connected to its plate terminal so they both perform the function of a plate); socket; A battery; B battery; milliammeter; voltmeter; 0-0.5 D.C. ammeter; variable resistance R_1 of 30 ohms; a variable high resistance R_2 of 50,000 ohms.

Explanatory Notes:

In Experiment 1 you found that when the filament is heated electrons are given off. If there were no plate within the tube, these electrons would form a sort of a miniature cloud around the filament, much like the cloud of water vapor which hovers over a pan of boiling water. These electrons would have no particular place to go and since they are all negative charges of electricity, would return to the filament.

With a plate P or second electrode seated in the glass tube and kept at a positive charge or potential with respect to the filament, by connecting it to the positive terminal of a second battery (called the "B" battery) as shown in Figure 1 or to some other source of direct current, it will attract the negative electrons to it (a positive charge attracts a negative charge). These negative electrons in motion constitute a flow of electric current. This is the very fact you discovered in Experiment A. Instead of using a "B" battery you made the plate positive by connecting it (through a galvanometer) to the positive terminal of the filament. Furthermore, in that experiment you found that when the plate was negative there was no plate current

From the preceding it is evident that in order to have current flow from the plate to the filament; (a) the filament must be heated and (b) the plate must be positive. In this experiment you will discover how the plate current of a two-electrode tube may be varied either by varying the plate potential or the filament current (temperature of the filament).

Procedure:

Part 1.

Connect the two-electrode tube as shown in Figure 1. Set the filament current constant at some value less than rated. Example: If the rated filament current is 0.25 amps use 0.2 amps. Starting with zero plate voltage, take reading of the plate current and voltmeter for each increase of voltage of 15 volts in the plate potential until rated value is reached.

Sketch:

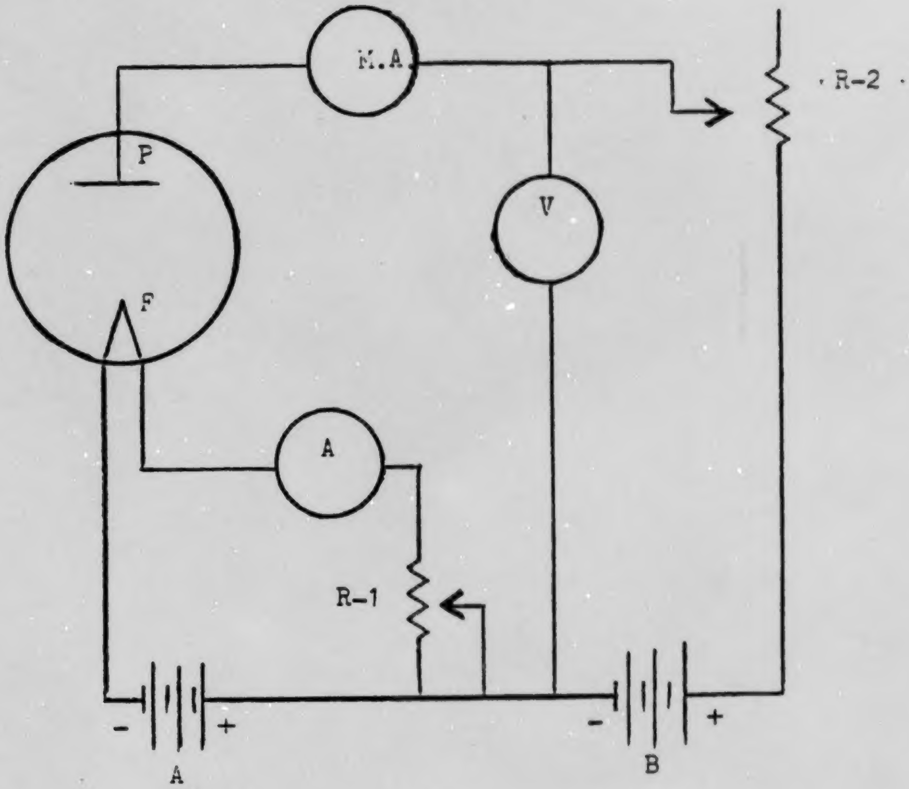


Fig. 1

Repeat the test with the filament current set at rated value (example 0.25 amps.).

Plot a graph with plate voltages as abscissae (horizontal) and plate current in milliamperes as ordinates (vertical). Do this for each of the two sets of readings.

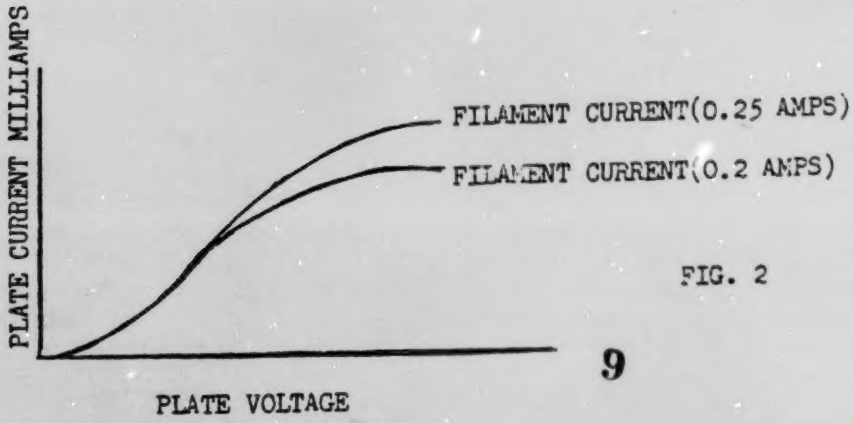


FIG. 2

Part 1. (Continued)

If you have been thorough in your work, the curves will be somewhat like the two shown in Fig. 2.

A study of Figure 2 shows that for a given value of filament current, that as the plate voltage is increased, there is a rapid increase in the plate current at first. After a certain value of plate voltage is applied, there is no appreciable increase produced in the plate current by increasing the plate voltage.

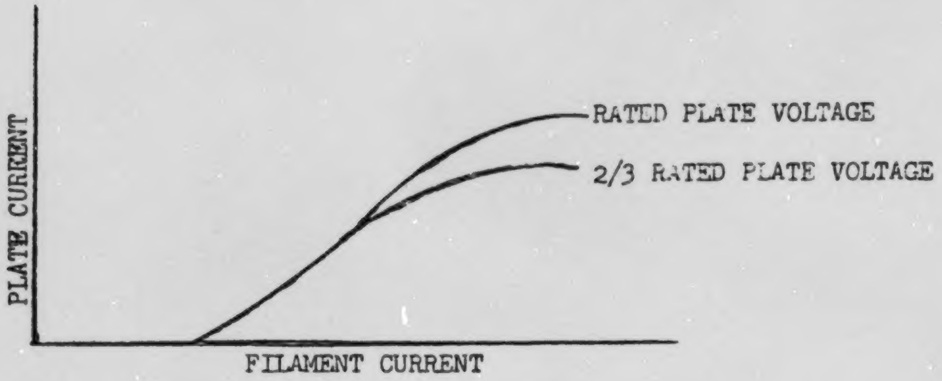
A further study of Figure 2 shows that for the low values of plate voltage, the plate current follows the same curve for different values of filament current, but for the upper end of the curve, more plate current is produced by a larger filament current.

Part II.

Repeat the experiment by keeping the plate voltage constant (2/3 rated value). Vary the filament current and plot a curve similar to that in Figure 3.

Repeat holding the plate voltage constant at rated value. Again vary the filament current.

FIG. 3



Questions:

1. What is an electron?

2. How does an increase in temperature (increasing a filament current) affect the number of electrons given off from a filament? (Study Figure 3).

3. In a vacuum tube why does the plate current flow in only one direction?

4. Why must the plate in a vacuum tube be kept relatively cold?

5. (a) Why is the plate current stronger when the filament is bright than when it is dim?

   (b) Does it continue to increase indefinitely as the filament current and temperature are increased? (Study Figure 3).

6. (a) How does the plate current of a tube vary as the plate voltage is increased? (Study Figure 2).

   (b) Can the plate current be increased indefinitely by increase of plate voltage? (Study Figure 2).

7. Why are the elements sealed in a glass bulb from which the air has been exhausted?

8. Explain two ways of increasing the plate current in a two-electrode vacuum tube.

9. Explain how the two-electrode tube may be used as a rectifier.

References:

Ghiradi - RADIO PHYSICS COURSE, 2nd Edition - Pages 382-397
Slack - ELEMENTARY ELECTRICITY - Pages 252-254
Swoope's - LESSONS IN PRACTICAL ELECTRICITY - Page 587

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BASIC ELECTRONICS

Job Sheet 3
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The Diode as a Rectifier

Objectives:

1. To study the use of diodes as a half-wave rectifier.
2. To study full wave rectification.

Materials Required:

Oscilloscope; VTVM; Power Supply (AC); 2 diode tubes - (6V volt filaments); 2 tube sockets; 5 watt 10,000 ohm resistor with taps.

Information:

A diode tube connected with DC voltages is simply a variable rheostat. If we place AC voltages to the input circuit we can change the output voltages to DC as the tube is a one way valve that conducts only when the plate is positive.

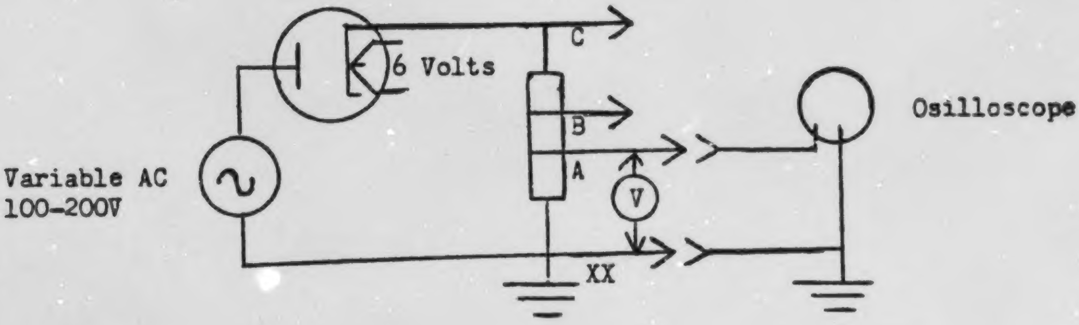

Fig. 1 Half-wave rectifier circuit.

Procedure:

1. Connect circuit as shown in Fig. 1.
2. Set oscilloscope at points "X" and "A" with AC voltage set at 100 volts. Record voltage.
3. Move "A" leads of scope and voltmeter to "B", record voltage and watch oscilloscope.

4. Move leads from "B" to "C", record voltage and watch oscilloscope.

5. Increase AC voltage in steps of 20 volts until 200-volts is reached repeating steps 2, 3, and 4. Make a chart and graph.

FULL WAVE RECTIFICATION

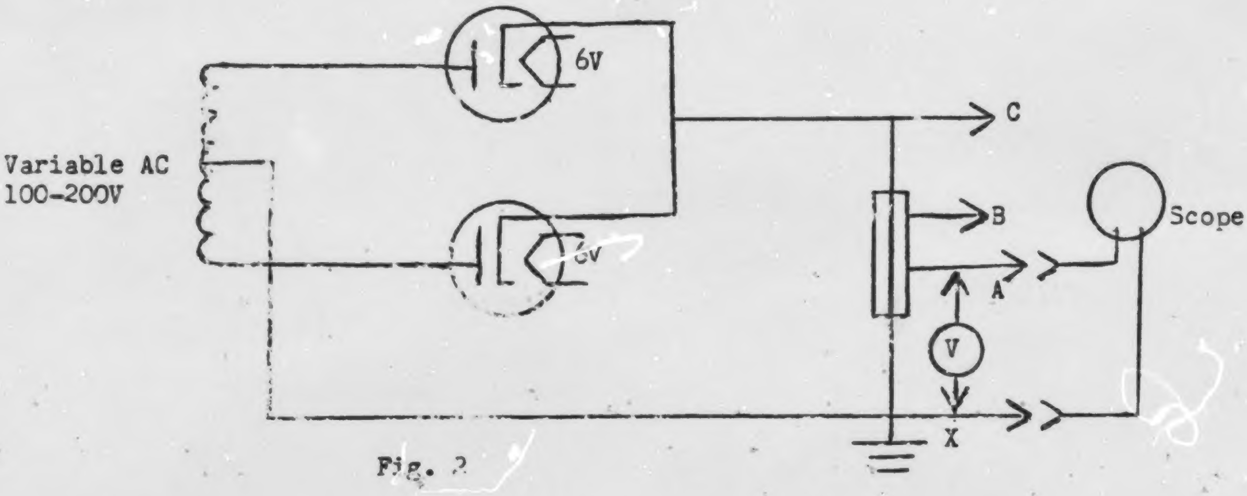

Fig. 2

Procedure:

1. Connect circuit as in Fig. 2

2. Repeat Steps 2, 3, 4, and 5 above. Make another chart and graph.

Questions:

1. In the half-wave rectifier circuit, does the voltage increase as you move the lead from "A" to "B" to "C"? Explain your answer.

2. Are the voltages higher with full-wave rectification? Why?

3. What is the oscilloscope recording?

4. What type of voltage does the oscilloscope show?

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Job Sheet 4
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Power Supply Circuits

Objectives:

1. To wire up a power supply using a transformer, full wave rectifier, and filter.
2. To make voltage, resistance, and waveform checks.
3. To determine the regulation.
4. To modify the basic supply to provide B+ and B-.
5. To wire up a transformer half-wave supply.

Materials Required:

Equipment: 0-100 Milliammeter, Oscilloscope, VTVM
Resistors: 10 watts, 25,000 ohm; 20 watts, 10,000 ohms; ½ watt, 2,200 ohm.
Capacitors: Two 20-uf, 450 volts; 20-uf, 150 volts.
Tubes: 5Y3, 6J5
Miscellaneous: Power Transformers (50 ma) with 5-volt and 6.3 volt fialment windings, 8-henry 50-ma choke.

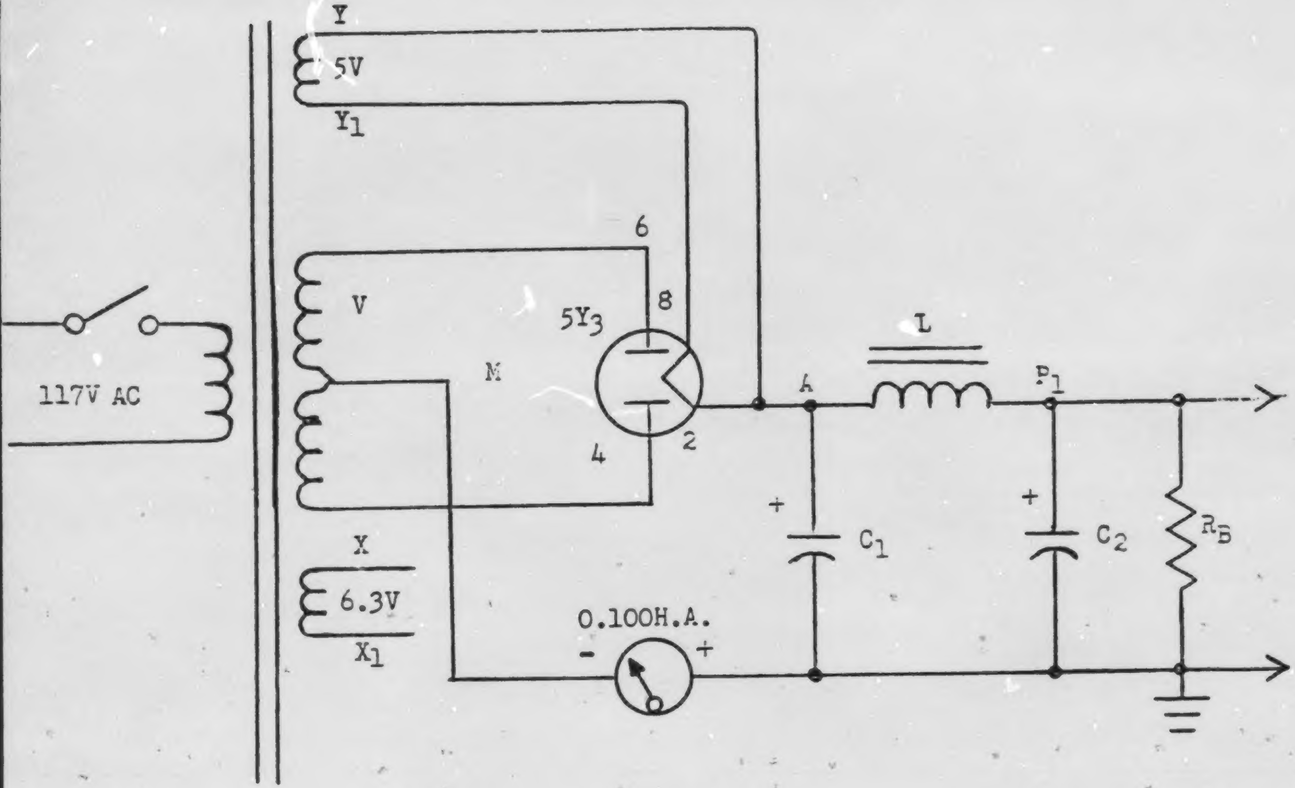
Introductory Information:

Direct-current voltages are required in radio to supply the vacuum-tube elements with their rated voltages. However, because its transmission is more efficient and economical, A C power is distributed throughout most sections of the country. This necessitates the rectification (changing) of A C into D C voltages. Electronic rectifiers and filters accomplish this. Figure 1 is the circuit diagram of a transformer full-wave rectifier power supply. V_1 is a rectifier with a directly heated cathode. The high-voltage secondary is connected to the plates of the rectifier. The center tap is connected to the ground return of the circuit.

C_1, L, and C_2 constitute a π filter, capacitor input, and R_B is the bleeder resistor.

The output B+ voltage depends on the A C voltage across the high-voltage secondary, the extent of load current I_L, and the size of the filter capacitors and choke. Without any load the D C voltage across C_1 is approximately equal to the peak voltage from either plate to common.

If a power supply is allowed to operate near peak voltage, it will result in poor voltage regulation. In order to provide better regulation, a certain minimum current must be drawn from the supply at all times. Any additional variations in load current cause a voltage drop across the rectifier tube and across the resistance of the choke L. The greater the load current I_L, the greater are the voltage drops I_LR across the choke and tube, and hence the lower is the B+ voltage which can be delivered to the load.



The regulation of a supply is an index which shows how B+ voltage varies as it is loaded. The formula for percentage of regulation is:

$$\text{Per cent regulation} = 100\ \frac{E_1 - E_2}{E_2}$$

where E_1 = no-load voltage - where E_2 = full-load voltage.

Regulation is improved by the use of a bleeder resistor R_B. This provides bleeder current under all load conditions. R_B also rapidly discharges C_1 and C_2 when power is shut off. Otherwise, these capacitors might become a shock hazard by carrying a charge for long periods of time after power has been removed. For improved regulation the bleeder current should be about 15 to 20 per cent of total current.

A D-C voltage exists at point P_1 (B+) to ground. This point is well filtered for normal B+ applications. Point A, the input to the filter, is not as ripple-free as point P_1. The ripple voltage at A and at P_1 increases with load. However, B+ should have a very low ripple voltage, even at full load. It is possible to observe and measure the ripple voltage with an oscilloscope. It may also be measured with an A C voltmeter.

Under normal operation alternating current is present across the primary (the line voltage) and across the secondary windings. The A-C voltage across the filament windings is measured across YY' and across XX'. The A-C voltage in the high-voltage secondary is measured from each of the rectifier-plate connections to the center tap, M. Plate-to-center-tap voltages should be approximately equal.

Opening either rectifier-plate connection causes the full-wave rectifier to become a half-wave rectifier. For the same load conditions, B+ drops because now only one of the diodes is supplying the load current instead of two. There is a greater drop across the tube, and the ripple frequency changes from 120 cps for full-wave rectification to 60 cps for half-wave action. (This is based on a line frequency of 60 cps.) At the lower frequency the filter is not as effective and the ripple voltage is therefore higher. Full-wave rectifiers are normally used for applications requiring high load current.

Table model and small console radios frequently use half-wave rectification.

It is sometimes necessary to provide a source of B- (for bias) as well as B+ voltage. A simple modification of the basic circuit, as in Fig. 2, accomplishes this. The circuit is essentially the same except that R_B has been replaced by two resistors, R_{B1} and R_{B2}, and filter capacitor C_3. The junction of R_{B1} and R_{B2}, point G, is chosen as the reference or "ground" point. Point P_1 is positive and P_2 is negative with respect to G. B+ is therefore taken from P_1 to G, and B- from P_2 to G. The resistance ratio of the divider R_{B1} and R_{B2}, in conjunction with the equivalent load resistance determines the amplitude of B+ to B- voltage. It should be noted that here the total value of voltage from B+ to B- for similar loading conditions is the same as B+ to ground in the circuit of Fig. 1. The circuit of Fig. 2 has not increased the total D-C voltage output of the power supply. It has reduced the available B+ from P_1 to G.

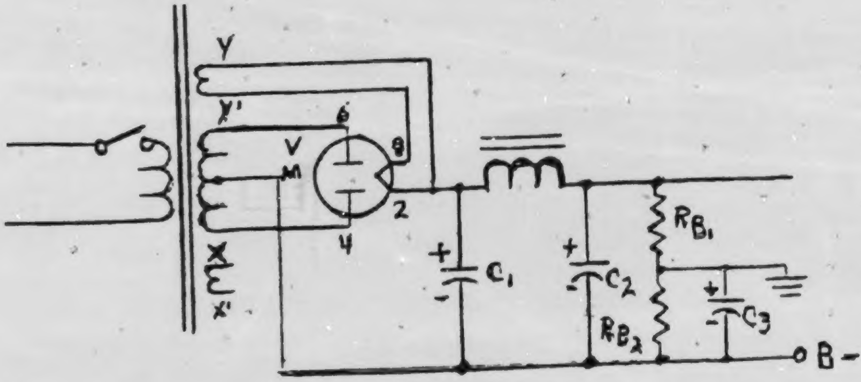


Fig. 2 Power supply connected to furnish B+ and B-

C_1, C_2, and C_3 are electrolytic capacitors and it is therefore necessary to observe proper polarity in connecting them in the circuit. Note that the polarity of C_3 has been properly indicated because G is effectively positive with respect to P_2.

Voltage and ripple measurements constitute one of the checks to determine the proper operation of a power supply. Resistance measurements are another check. Before resistance is measured, power should be removed and all filter capacitors discharged. Resistance measurements are made from B+ to ground to determine whether C_1 or C_2 is shorted. Other resistance measurements may be made to determine continuity of the windings, the choke, and the bleeder resistor. When you make a filament continuity test, it is best to remove the tube in question from its socket. This avoids erroneous readings due to the continuity of parallel paths such as the transformer filament winding or other tube filaments.

In measuring resistance across a good electrolytic capacitor which is not in parallel with a resistor, the meter will first indicate a low resistance value. If the meter prods are kept across the capacitor, the resistance will increase with time. What is happening is that the capacitor is being charged by the ohmmeter battery. The capacitor-charging current which flows through the meter movement decreases with time. Hence the ohmmeter registers an apparently increasing resistance. The value of charging current will change if meter polarity is reversed, and therefore the apparent resistance will differ with reversed polarity.

If there is a resistor in parallel with the capacitor, the capacitor will charge and the ohmmeter will then read the value of the parallel combination of capacitor leakage and the resistor.

Procedure:

Full-wave Supply

1. Connect the circuit of Fig. 1. C_1 and C_2 are 20-μf, 450-volt capacitors. R_B is a 25,000-ohm 10-watt resistor. The 6.3-volt filament supply (XX') is connected to the filaments of a 6J5 as in Fig. 3.

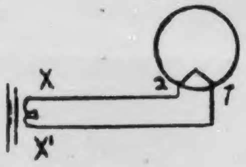


Fig. 3. Filament connections.

CAUTION: The milliammeter M should be set on the 100-ma range. Note Fig. 1 and observe proper polarity in connecting meter and capacitors in the circuit.

2. With an oscilloscope observe the waveform at the plates of the rectifier with respect to M, the ground return. Record these, showing proper polarity (2 cycles). Measure with an A-C voltmeter and record rms voltage.

3. Measure and record in Table 1 the D-C no-load voltage at P (B+) and at A.

TABLE 1. Full-Wave Rectifier

	No-load				10,000-ohm 20-watt load			
	D-C volts	Ripple waveform	A-C volts	I_B	D-C volts	Ripple waveform	A-C volts	I_T
P								
A								

4. Observe, measure with a scope and with an A-C voltmeter, and record in Table 1 the ripple waveform and voltage at P_1 and at A.

5. Check ripple frequency and record.

6. Measure and record the bleeder current I_B flowing in the circuit.

7. Turn power OFF and connect a 10,000-ohm 20-watt load resistor R_L in parallel with R_B.

8. Turn power ON. Repeat Steps 3, 4, and 5. Record measurements in Table 1 in "10,000-ohm load" column.

9. Measure and record the A-C voltage across the rectifier filament and across the filament of the 6J5.

10. Power Off. Remove milliammeter from the circuit and connect center tap MK to ground.

11. Measure resistance at all points indicated in Table 2 with and without R_B and R_L.

Full-Wave Supply for B+ and B-

1. Connect the circuit of Fig. 2. C_1, C_2, and L have same values previously used. R_{B1} is a 25,000-ohm 10-watt resistor, R_{B2} is a 2,200-ohm 1/2-watt resistor. C_3 is a 20-μf 150-volt capacitor. Connect 10,000-ohm 20-watt load from B+ to B-.
2. Power On. Measure and record in Table 3 the D-C voltage from B+ ground, B- to ground, and B+ to B-.
3. Observe, measure with a scope and A-C voltmeter, and record in Table 3 the ripple waveform and A-C voltage from B+ and B- with respect to ground.

TABLE 2

	Resistance	
Point of measurement	R_B and R_L in circuit	R_B and R_L out of circuit
P_1 to ground		
A to ground		
A to P_1		
Pin 6 of 5Y3 to ground		
Pin 4 to 5Y3 to ground		
Pin 4 to pin 6 (5Y3)		
XX'		
YY'		

TABLE 3

Point	D.C.Volts	Ripple	
		Waveform	A-C Volts
B+ to ground			
B- to ground			
B+ to B-			

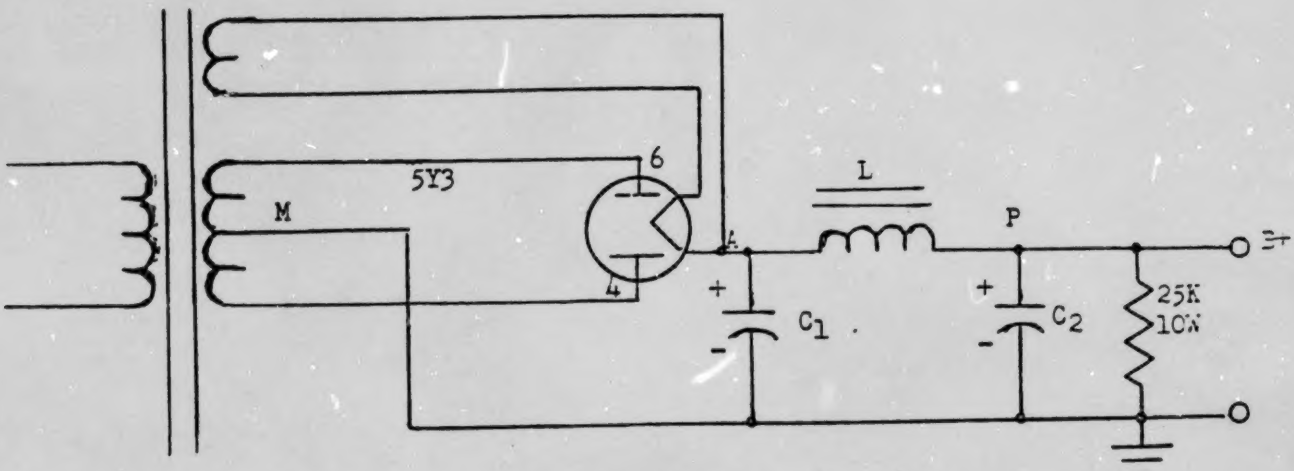


Fig. 4 Half-wave power supply

Half-Wave Supply

1. Power Off. Connect the circuit in Fig. 4. C_1, C_2, and L have the same values used previously.
2. Power On. Measure and record in Table 4 the D-C no-load voltage from points P_1 (B+) and A with respect to ground.
3. Observe and measure with respect to ground the ripple voltage with no load at P_1 and A and record in Table 4.
4. Power Off. Add a 10,000-ohm 20-Watt load from B+ to ground.
5. Power On. Repeat Steps 2 and 3 for the 10,000-ohm load.

TABLE 4

Half-Wave Rectifier Measurements with and without load

	No-Load			10,000-ohm 20-Watt Load		
	D-C Volts	Ripple		D-C Volts	Ripple	
		Waveform	A-C Volts		Waveform	A-C Volts
P_1						
A						

Questions:

1. Compare the full-wave and half-wave supplies (Figs. 1 and 4) under conditions of 10,00-ohm load as to a D-C voltage; b. Ripple voltage at output.

2. a. What is the regulation of the full-wave and half-wave supplies?
   b. Explain differences, if any, in regulation.

3. What is the purpose of a bleeder resistor?

4. Explain how you can determine if (a) Choke L is open. (b) Any of the transformer windings is open. (c) The center tap M is open.

5. a. What is meant by line isolation?
   b. Explain how B+ is isolated from the line in Fig. 1.

6. a. Detail a means by which a source of -10 volts can be obtained from a transformer-operated receiver which draws a total of 60 ma.
   b. What happens to the B+-to-ground voltage?

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Job Sheet 5
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Power Supply Filters

Objectives:

1. To study and compare the effectiveness of the different types of filter arrangements.
2. To observe the effects of each of the filter elements on D-C voltage output and ripple.

Materials Required:

Same as in Job 4. In addition: a 500-ohm 5-watt resistor.

Introductory Information:

The effect of rectifying an A-C voltage is to change it into a pulsating D-C voltage. The output of the full-wave rectifier of Fig. 1 requires smoothing or filtering to transform it into a steady D-C voltage. Capacitors, chokes, and resistors are used in various filter arrangements to accomplish this.

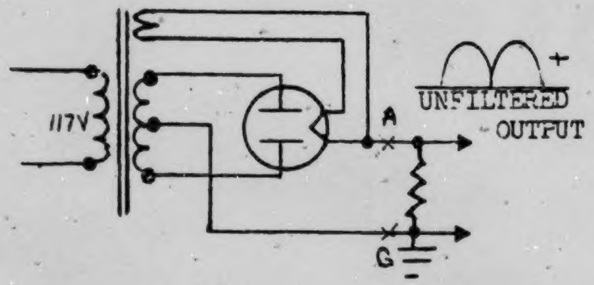

Fig. 1. Unfiltered output of full-wave rectifier.

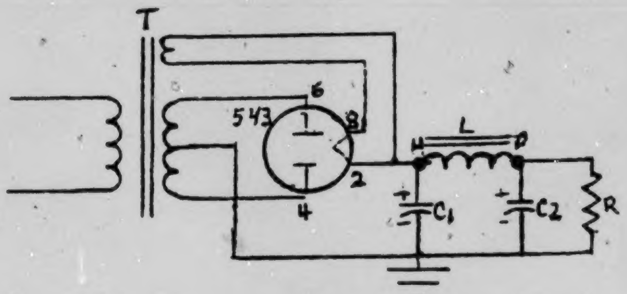

Fig. 2. Rectifier with filter.

1. Capacitor-Input Filter

In Fig. 2, C_1, L, C_2 constitute a π-type capacitor-input filter. A characteristic of this type of filter is that it provides maximum voltage output for the load. Electrolytic capacitors C_1 and C_2 are usually 10 to 20 uf for radio receivers. The size of C_1 is limited by the rectifier tube and and transformer impedance, and its maximum value is usually specified. The voltage rating required for C_1 is higher than C_2 , b-cause C_1 takes the initial charge and actually operates at a higher potential than C_2.

The size of the iron-core choke coil L depends on the amount of load current required. A characteristic of the choke is to oppose a change in current, while a characteristic of the capacitor is to oppose a change in voltage. The filter tends to average out the rectified pulses by clipping the peaks and filling in the valleys and thus supplies a constant voltage to the load.

The D-C voltage drop across the choke L depends on the load current I and on the resistance R_L of the choke. It is apparent that as the I increases, the voltage drop across L increases and hence the output voltage at B decreases. For high current loads, therefore, a large inductance with low internal resistance is used.

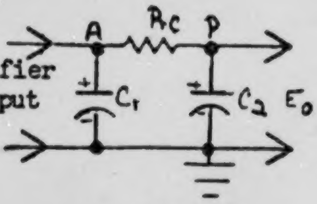

Fig. 3.
Resistor (R_C)
used in type filter.

Frequently, where current and voltage requirements are low, a resistor is used to replace the choke. Figure 3 illustrates this type of filter. The resistance R_C is usually larger than the internal resistance R_L of the choke. There is more ripple in the output than with a choke. However, the increased ripple may be offset by the use of larger-capacitance electrolytics.

2. Choke-Input Filter

For some applications where there are relatively large variations in load current, better regulations may be required than is possible with a capacitor-input filter. The use of a choke-input filter with a specified minimum bleeder current (Fig. 4) provides the improved regulation required. However, the output B+ voltage, other conditions being the same as in the circuit of Fig. 2, is lower than that previously realized. Of course, the addition of an extra choke has improved the filtering.

The power transformer and the choke coil or coils must be capable of handling the maximum load current requirements. Thus, if 90 ma of load current is to be supplied, the choke must be rated somewhat higher. The same is true of the D-C rating for the high-voltage secondary of the power transformer T.

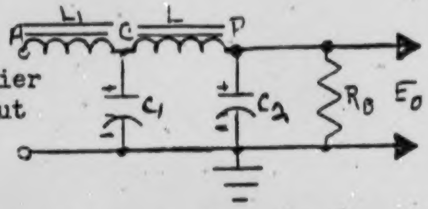

Fig. 4. Choke-input filter.

The effect of a leaky capacitor C_1 or C_2 is to reduce the output voltage. Moreover, the ripple voltage increases. If capacitor C_1 or C_2 is is open, it reduces D-C voltage with a consequent high increase in ripple. An open choke L will not permit any D-C voltage to appear at point P, the output.

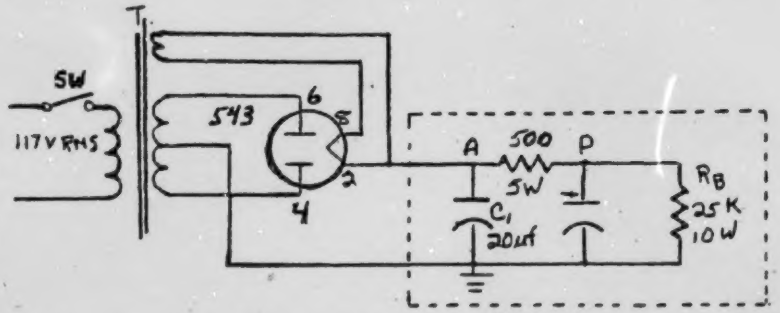

Fig. 5. Full-wave supply with π-type RC filter and bleeder

Procedure:

1. Connect the circuit of Fig. 5. The filter network is shown enclosed by dashes, The 25,000-ohm 10-watt resistor is a bleeder (not a load).
2. Power On. Measure the record in Table 1 the D-C no-load voltage at P and A.
3. Observe and measure with a scope and record in Table 1 the ripple wave form at P and A.
4. Power Off. Add a 10,000-ohm 20-watt load resistor R_L in parallel with R_B.
5. Power On. Repeat Steps 2 and 3. Record measurements in Table 1 in "10,000-ohm" column.
6. Power Off. Remove C_1 from the circuit.
7. Power On. Repeat Step 5.
8. Power Off. Replace C_1 and remove C_2 from the circuit.
9. Power On. Repeat Step 5.
10. Power Off. Replace the filter network with that of Fig. 6.
11. Power On. Repeat Steps 2 through 9 for the new filter circuit.
12. Power off. Replace the filter network with that of Fig. 7.
13. Power On. Measure and record the D-C voltage at P.

CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

Job Sheet 6
Page 1 of 3

The Three-Electrode Vacuum Tube - The Action of the Grid

Purpose:

To discover the function of the grid in a vacuum tube.

Materials Used:

Three-electrode vacuum tube; 0-10 milliamperes; 0-15 range voltmeter; C battery (variable); B battery; A battery.

Explanatory Notes:

The three-electrode tube is essentially the same as the two-electrode type, but has in addition a third element called the grid. The grid which is in the form of a metallic mesh, (usually fine wire with widely spaced turns, wound close but not touching the filament), is placed between the filament and the plate. It is represented by the wavy line G in Figure 1.

In Exp.   you discovered in a two-electrode tube, with a given filament temperature, the rate of flow of electrons (plate current) depends on the potential of the plate. The question now arises what will be the effect of a third electrode (grid) inserted between the filament and plate, upon the electrode which must pass through its open spaces on their way to the plate? You will discover this answer in performing this experiment.

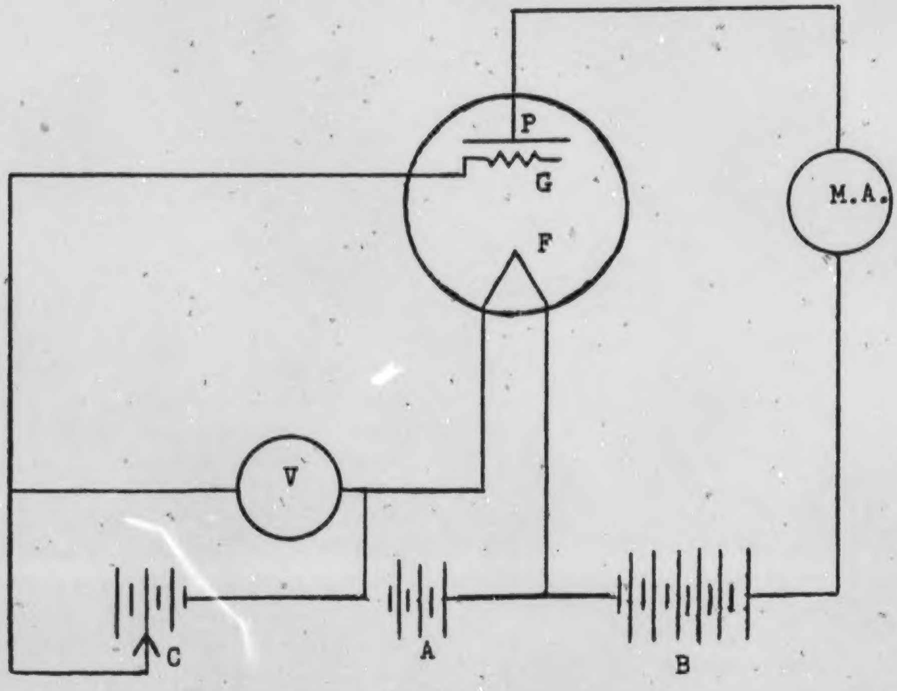

FIG. 1

Procedure:

Connect the three-electrode tube as shown in Figure 1. Apply rated voltage (A battery) to the filament. Apply rated voltage (B battery) to the plate. Make the grid positive by connecting the positive terminal of the C battery to its electrode.

Starting with zero grid voltage, take reading of the plate current and grid voltage for each increase of grid voltage of approximately two volts.

Repeat with the battery connections reversed (grid negative).

Plot a graph with grid voltages as abscissae and plate current as ordinates.

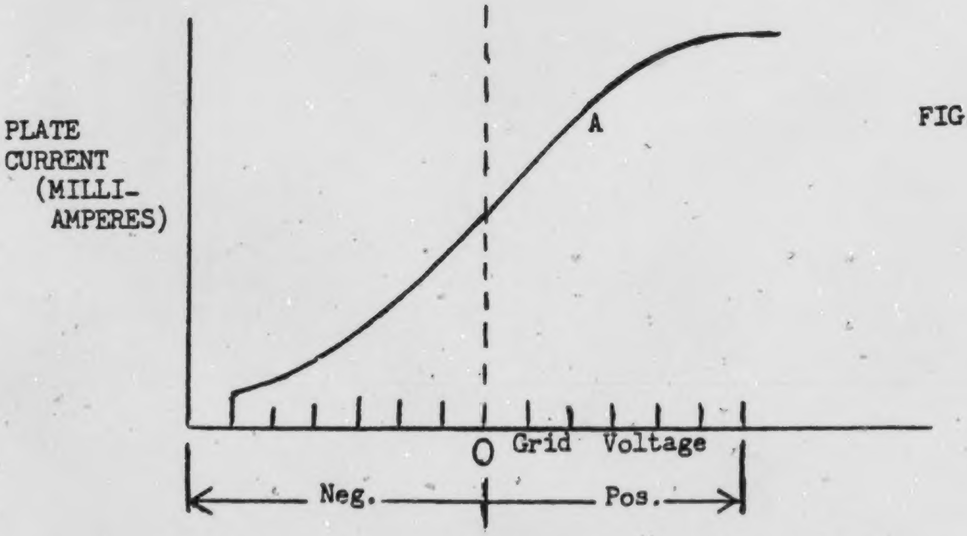

FIG. 2.

If you have been thorough in your work, the curve will be somewhat like the one in Figure 2.

Point A is the value of plate current when grid voltage is zero. Values to the right of A are for positive grid voltage and those to the left of A are for negative grid voltages.

The plate voltage and filament current were constant throughout the test. At zero grid potential (point A on the curve) the plate current has a definite value. As the grid potential is made more and more positive the plate current increases. As the grid potential is made more and more negative, the plate current decreases. With sufficient negative grid potential the plate current is stopped entirely. The grid, therefore, acts like a valve in controlling the flow of electrons (plate current) in the tube. It is to be noted that small variations in the grid voltage may produce enormously greater changes in the plate current. In radio work the grid is not allowed to go positive. The signal applied to the grid makes the grid more or less negative as the value of the signal changes. Making the grid less negative increases the plate current.

The Action of the Grid

In Experiment you found that the plate current can be varied by varying either the filament current or the plate potential. In this experiment you discovered a third way, namely, varying the grid potential. Since the grid of the tube is much nearer to the filament than the plate when a potential is applied to the grid it can control the electron emission much more effectively than the same potential applied to the plate.

Example: In a 224 type tube a change in the grid voltage will produce 400 times as much plate current change as an equal change in the plate voltage will. In other words, it requires 400 times the number of volts change in the plate circuit to affect the plate current to the same extent as that accomplished by the grid. The voltage amplification of the 224 tube is 400.

The effect of the grid in either increasing or decreasing the electron flow and hence the plate current enables us to control comparatively large currents in the plate circuit by applying very small variations of potential upon the grid circuit.

Questions:

1. What are the functions of the three vacuum-tube elements, namely: filament, plate and grid?
2. (a) Name three ways of varying the plate current.
   (b) Tell which method is most effective.
3. (a) What is "space charge"?
   (b) How does it affect the operation of the tube?
   (c) Is it desirable?
4. (a) What is the grid?
   (b) What is the effect of the grid in the three-electrode tube?
5. Explain how the three-electrode tube can be used as an amplifier.
6. (a) Describe the construction of a three-electrode tube.
   (b) Explain its operation.

References:

Slack - ELEMENTARY ELECTRICITY - Pages 263-266
Ghirardi - RADIO PHYSICS (SecondEdition) - Pages 396-400
Swoope's LESSONS IN PRACTICAL ELECTRICITY - Page 589

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Information Sheet
Page 1 of 2

THE TRIODE TUBE

Objectives:

To become familiar with the triode tube, its uses and construction.

Introductory Information:

In 1906 Lee DeForest placed another electrode inbetween the cathode and the plate of the diode tube and discovered that the tube was then able to amplify and made a great advance towards electronics as we know it today.

Body of Information:

The invention of the triode was an extremely important advance in electronics because it permitted electronic "amplification". Basically, the triode is nothing more than a diode to which has been added a third electrode - a grid. The physical dimensions of the grid determine many of the operating characteristics of the triode.

The basic function of the grid is to control the movement of electrons between the cathode and the plate, thereby controlling the amount of plate current flowing in the tube. It is for this reason that this third electrode is called the control grid. Because it is so very close to the cathode, the voltages on the control grid exert much more influence on plate current than do voltages on the plate. All plate and grid voltages are measured with respect to the cathode. D.C. plate voltages are known as "B" voltages, D.C. grid voltages (called bias) as "C" voltages, and heater, or filament voltages as "A" voltages.

The grid acts like a gate that allowed electrons to pass or to keep them from passing. If the grid is slightly negative, it will slow down the electron flow, thereby lowering the current in the plate circuit. If the grid is made greatly negativ, it can stop the flow of electrons and halt current in the plate circuit. This is called grid cut off voltage. If the grid is positive, it will speed up the flow of electrons reducing the space charge and causing saturation in the electron flow. The control grid is most commonly operated at a voltage slightly negative with respect to the cathode.

The basic triode circuit consists of the grid-cathode portion called the input and the plate cathode called the output. In this circuit, all input voltages or signals are applied between the grid and the cathode; all output voltages or signals appear between the plate and the cathode. The voltages applied between the plate and cathode are usually between 100 and 300 volts.

The slight negative voltage applied to the control grid is called the grid bias voltage.

THE TRIODE TUBE

If an A-C voltage is placed in series with the fixed negative voltage, the voltage on the grid will alternately be more negative or less negative depending on the A-C voltage and the part of the cycle it is on. When the A-C voltage is on the positive alternation the grid voltage will be less negative and more electrons will flow in the plate circuit causing more current flow. When the A-C signal is on the negative alternation the grid voltage will be more negative and less current will flow in the plate circuit.

If a resistance is placed in the plate circuit, the voltage drop across it will continually change with the change in the grid circuit. This is the principal behind the amplification of the triode. The grid voltage does not go into the plate circuit but does cause a mirror image of itself in the plate circuit.

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Information Sheet
Page 1 of 1

USE OF A "B" BATTERY

Objectives:

To understand the purpose of a "B" battery in the plate circuit of a vacuum tube.

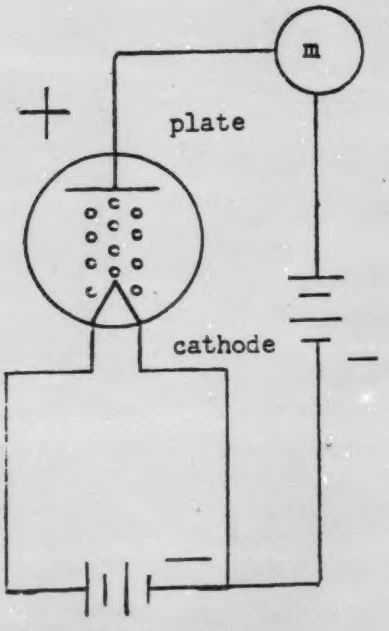
Body of Information:

If we connect a vacuum tube and heat the cathode, electrons having a negative charge would be given off and form a cloud near the cathode. This is known as a space charge.

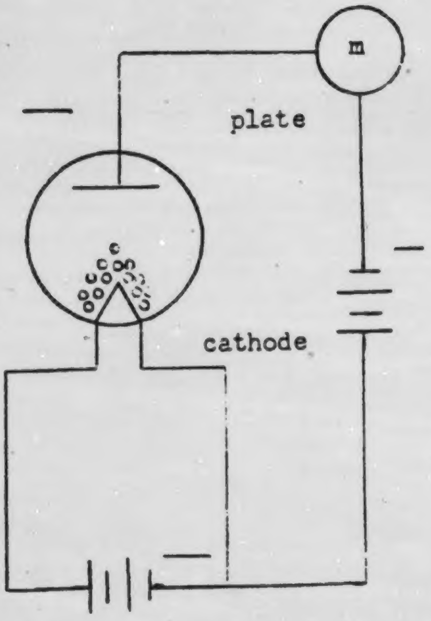
However, if we place a battery in the plate circuit with the positive plate of the battery to the tube, the positive charge of the plate will attract the electrons of the space charge and cause a current in the plate circuit.

If however, the battery is connected so that the negative plate of the battery is connected to the tube, no current will flow as the negative charge of the plate will repel the negative charged electrons of the space charge.

LIKE CHARGES REPEL. UNLIKE CHARGES ATTRACT.



Current flows



Current does not flow

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BASIC ELECTRONICS

Job Sheet 7A
Page 1 of 4

Amplifier Circuits

Objectives:

1. To become familiar with the circuit of a triode connected as a D-C amplifier.
2. To observe how a small change in D-C voltage at the grid is amplified by the tube and appears as a larger change in D-C voltage at the plate.
3. To locate the linear portion of the amplifier characteristic.

Materials Required:

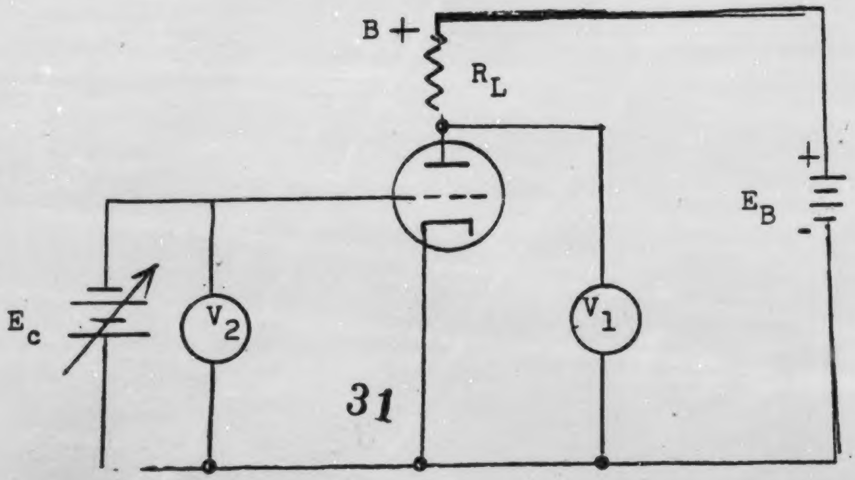
Power supply: Voltage source with 200-volt D-C output and 6.3-volt rms A-C output for filament voltage.
Equipment: Two voltmeters
Resistor: 1/2 watt, 22,000 ohms.
Tubes: 6J5

Introductory Information:

A D-C amplifier is a device which converts small D-C voltage changes into large D-C voltage changes.

The circuit of Fig. 1 shows such a voltage amplifier. E_B is a constant B+ source supplying plate voltage for the tube.

A variable source of bias voltage E_C is provided so that the voltage on the grid (E_g) may be varied to show the effects of D-C amplification in the plate circuit.



Introductory Information - Continued

R_L is connected between the plate and B+. When plate current flows through the tube, it also flows through R_L. For any particular value of grid bias, E_g, there is plate current, I_p, flowing through the tube and the voltage measured from plate to cathode is E_p. Applying Kirchhoff's voltage law to the tube circuit, it is evident that

$$E_B = E_p + I_p \times R_L$$

and therefore: $$E_p = E_B - I_p \times R_L$$

If E_g, the value of the grid bias, becomes more negative, the current through the tube will decrease and the voltage drop across R_L (I_pRL) will decrease. Therefore, E_p will increase. Similarly, if E_g becomes less negative, I_p will increase and E_p will decrease.

The extent of change of E_p for a specified change in E_g will depend on the tube characteristics, on the size of R_L, and on the value of E_B.

It is desirable where D-C amplifiers are used that the amplifier have a constant gain over its operating range. That is, a grid-bias change of 1 volt should produce the same plate-voltage change, whether the grid-voltage variation is from -3 to -4 volts or from -1 to -2 volts. It is possible to determine experimentally this linear operating range for a specific D-C amplifier circuit by graphing the E_p vs. E_g characteristic of the tube with the load resistor R_L in the circuit. The portion of this graph which is linear defines the range of operation over which the gain of the amplifier is constant.

Refer to Fig. 2. This is the graph of a triode connected as a D-C amplifier with plate load R_L. The graph shows that AB is the linear portion of the amplifier's characteristic and that in this region a change of 1 volt in the grid results in a 25-volt change at the plate. Moreover, the center of this linear portion is at M. At points A, M, and B, the values of grid bias are, respectively, -5, -3, and -1 volts, and the corresponding values of plate voltage are +200, +150, and +100 volts.

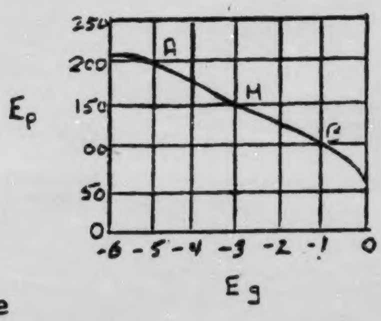


Fig. 2. Ep vs. Eg characteristic of a d-c amplifier with load R_L.

Introductory Information - Continued

The gain of a D-C amplifier over the linear portion of its E_p vs. E_g characteristic may be found from the formula

$$\text{Gain} = \frac{\Delta E_p}{\Delta E_g} \qquad (3)$$

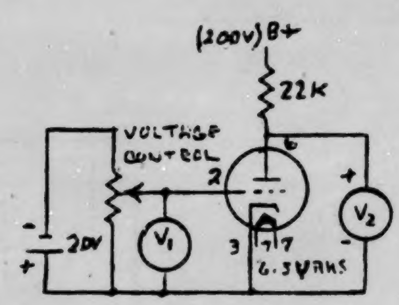


Fig. 3. Circuit for determining triode E_p vs. E_g characteristic.

where ΔE_p is a change in plate voltage corresponding to ΔE_g, a change in grid voltage. The gain of the triode-connected D-C amplifier whose characteristic is shown in Fig. 2 is

$$\frac{25}{1} = 25$$

Procedure:

1. Connect the circuit of Fig. 3. V_1 and V_2 are used to measure the grid bias (E_g) and plate-to-cathode voltage (E_p) of the 6J5.
2. Monitor and maintain the plate voltage source (B+) constant at 200 volts.
3. Set the voltage control so that $E_g = 0$. Measure and record in Table 1 the plate voltage E_p.
4. Repeat Step 3 for every value of E_g shown in Table 1.

TABLE 1

E_G	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14	-15
E_p																

5. Draw the graph of E_p vs. E_g (using E_g as abscissa and E_p as ordinate) on the graph of Fig. 4.
6. Locate points A, B, which bound the linear portion of the tube's E_p-E_g characteristic, and M, which is at the center of the linear portion. Mark these points on the graph. Indicate in Table 2 the values of E_g and E_p which correspond to Points A, B, and M.

TABLE 2

	Point A	Point B	Point M
E_g			
E_p			

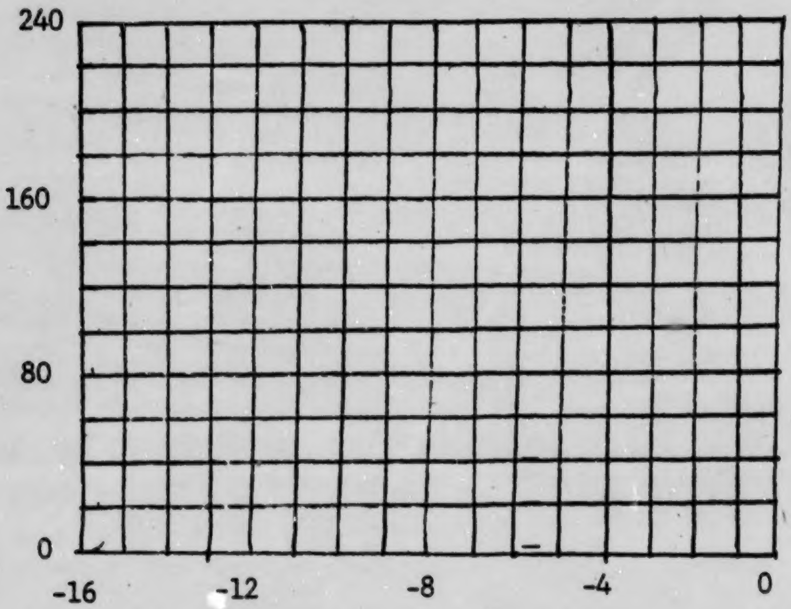


Fig. 4. Graph of E_p vs. E_g

7. Compute the gain of the amplifier. Show all computations.

Questions:

1. Compute the current in the circuit of Fig. 3 at points A, M, and B. Show all computations.
2. How does grid bias affect plate current in a triode?
3. What is meant by the gain of a D-C amplifier?
4. How does the gain of the amplifier in Fig. 3 compare with the rated u of the tube? Explain.
5. Compute I_p for each E_g in Table 1 and graph the E_g-I_p curve for this amplifier.

CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

Job Sheet 7B
Page 1 of 3

Amplifier Circuits

Objectives:

1. To demonstrate the ability of a triode to amplify an A-C voltage.
2. To show that a triode amplifier will distort an A-C voltage if it is not properly biased.

Materials Required:

Power supply:	Voltage source with +200-volt and -20-volt variable D-C output and 6.3-volt rms. A-C output for filament voltage.
Equipment:	VOM, VTVM, Oscilloscope
Resistors:	1/2 watt, 100,000-ohm, 22,000-ohm
Capacitors:	Two 0.01-uf
Tubes:	6J5
Miscellaneous:	500,000-ohm Potentiometer

Introductory Information:

In the A-C voltage amplifier an A-C signal voltage is fed to the grid current. This signal voltage is amplified and appears as a large signal voltage in the plate circuit.

Figure 1 is the circuit diagram of a triode connected as an A-C amplifier. An A-C voltage E_g is capacitively coupled to the grid of the amplifier. The grid is biased by a voltage source E_C with such polarity that it is negative with respect to the cathode. A plate-load resistor R_L is connected from plate to B+, which is a constant source of 200 volts.

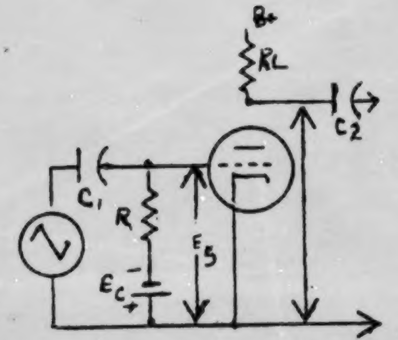


Fig. 1. Triode connected as a-c amplifier.

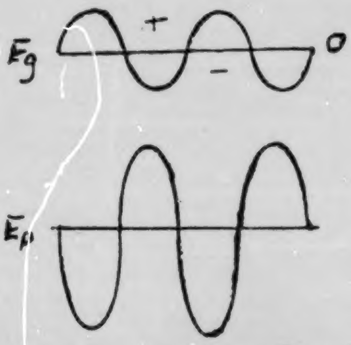


Fig. 2. Grid and plate voltage waveforms in a-c amplifier.

Introductory Information - Continued

The voltage variations E_p at the plate (with respect to cathode) result from the input-signal variation E_g. Figure 2 shows the input-signal sine wave at the grid and the resulting plate waveform. The signal voltage E_p at the plate is the result of triode amplification, and it is a distortionless reproduction of the input signal. That is, the amplifier has not distorted it.

Figure 3 shows a plate waveform which has been distorted by the amplifier. Note that the positive alternation has been flattened.

For distortionless amplification it is necessary that the amplifier operate over the linear portion of its E_g-I_p characteristic. In Fig. 4 the linear portion of the dynamic E_g-I_p characteristic is AB. M is the middle of this linear portion. Assume that $E_g = -5$, -3, and -1 volts and $I_p = 2$, 4, and 6 ma correspond, respectively, to the points A, M, and B. For distortionless amplification the tube is biased at -3 volts (in the middle of the linear range). The bias point is called the "operating point" of the tube. The maximum signal voltage (E_g) which may be injected into the grid and which can be amplified without distortion here is a 4-volt peak-to-peak signal, operating about M within the grid limits, -5 to -1 volts. Under these conditions the current waveform I_p in the plate circuit will follow the grid-signal waveform. The plate waveform E_p results from the plate current.

If E_g is larger than 4 volts, peak to peak, say it is 10 volts peak to peak, then the tube will introduce distortion both on the positive and on the negative peaks. On the negative peaks the tube will be cut off (note cutoff for the tube is here presumed to be -7 volts), and on positive alternations current will be nonlinear to the right of point B.

It is therefore apparent that the operating conditions for a tube must be properly set to accomplish distortionless amplification of a signal voltage.

The gain of an A-C voltage amplifier may be determined experimentally by comparing the output A-C voltage E_p or E_o with the input A-C voltage E_g or E_{in} It is given in the formula:

$$\text{Gain} = \frac{E_o}{E_{in}} \qquad (1)$$

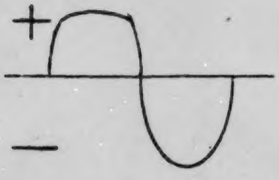


Fig. 3
Distorted waveform

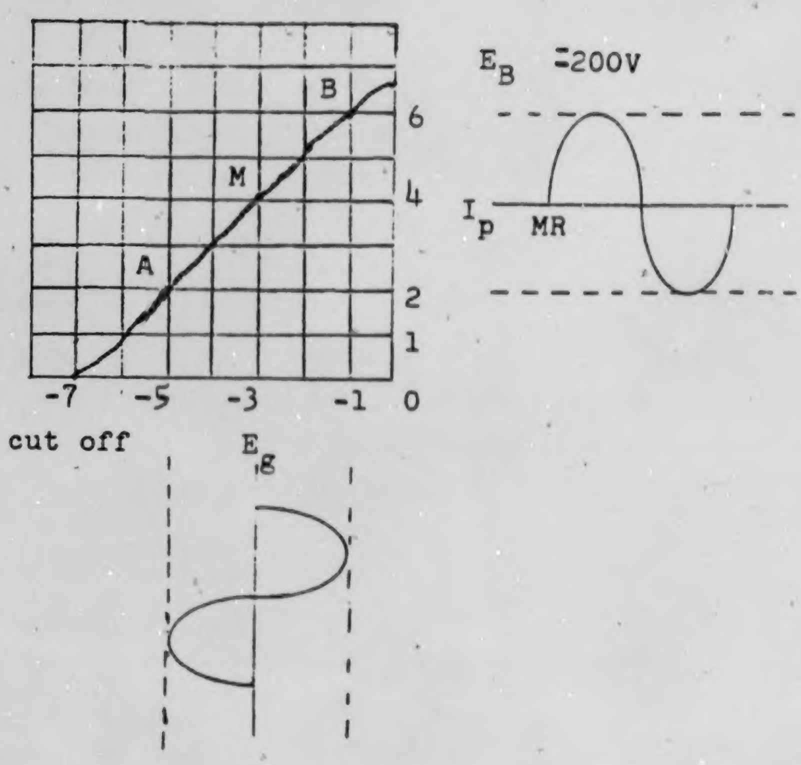


Fig. 4. Characteristic for triode amplifier with R_L as plat load.

Gain may therefore be found by measuring the input signal and the output signal and substituting the measured values in formula (1).

In this job you will first observe the effects of A-C amplification by a triode amplifier and will measure the gain of the amplifier. You will then note how distortion may be introduced if the bias is not properly set.

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BASIC ELECTRONICS

Job Sheet 8A
Page 1 of 10

Bias in Amplifiers

Objectives:

1. To study the operation of a class A audio voltage amplifier.
2. To observe the effect on output signal voltage of varying the plate-load resistor.
3. To determine the voltage gain of an audio amplifier.
4. To study the signal-voltage distribution of an RC network coupling the signal from the plate circuit to a voltage amplifier.
5. To determine what constitutes the A-C plate load.

Materials Required:

Power supply: Variable + and - direct current, 6.3-volt rms.
Equipment: Oscilloscope, VTVM, and audio source.
Resistors: 1/2 watt, 10,000-ohm, two 100,000-ohm, 270,000-ohm, 470,000-ohm, two 1-meg, 4.7-meg.
Capacitors: 0.01 uF and 0.05 uf.
Tubes: 6SQ7 and 6J5
Miscellaneous: 500,000-ohm 2-watt pot, high-impedance earphones.

Introductory Information:

1. The Class A Amplifier

The ability of a triode to amplify a signal voltage was demonstrated in Job 7B. In this job the operation of a class A voltage amplifier will be studied. The use of a class A voltage amplifier as an audio amplifier will also be considered.

Figure 1 is the circuit diagram of a voltage amplifier. Here a triode tube is used. The load is a resistor R_L, connected from the plate to B+. R_g is the grid resistor which is in series with the bias voltage E_c. C is a capacitor which couples the signal voltage e_g to the grid of the tube.

The class of operation of the amplifier depends on the bias E_c. A class A amplifier is one in which the grid bias is set so that plate current in that amplifier flows at all times for the range of a signal voltage that it is capable of handling.

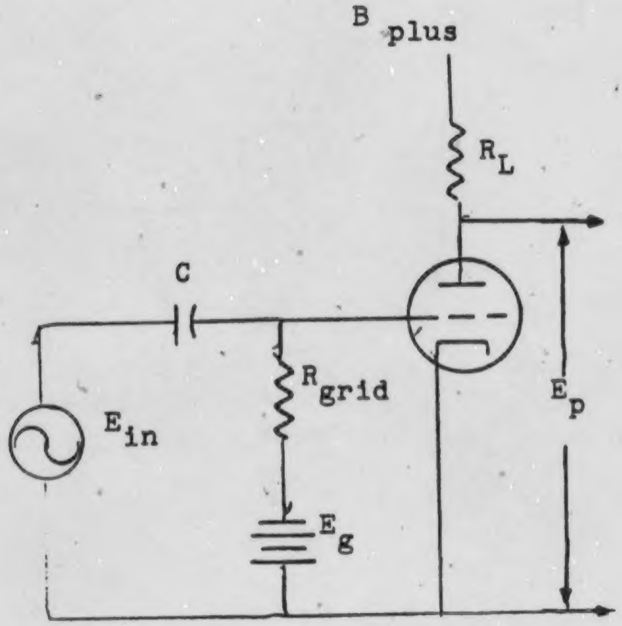


Fig. 1. Class A audio amplifier

The grid bias sets the operating point of the amplifier. Consider the e_g-i_p characteristic curve (Fig. 2) of the amplifier Fig. 1. This curve shows that the amplifier's bias has been set at -10 volts and that the grid signal varies around this voltage. The "operating point" is -10 volts. The linear portion of the amplifier's characteristic curve lies between points A and B. At point A the grid-to-cathode voltage is -19 volts and the plate current is 1 ma. At point B the grid-to-cathode voltage is -1 volt and the plate current is 21 ma. The operating point for this amplifier was chosen so that it is in the middle of the linear portion of the characteristic. The point P on the curve corresponds to the operating point, and at P, 11 ma of current flows.

Without any signal voltage, the grid-to-cathode voltage is -10 volts and 11 ma of current flows. If an 18-volt peak-to-peak sine-wave signal is capacitively coupled to the grind of the amplifier, the signal voltage will vary the grid-to-cathode voltage from -10 to -1 volts on the positive alternation and from -10 to -19 volts on the negative alternation. The current in the plate circuit will vary sinusoidally between 1 and 21 ma.

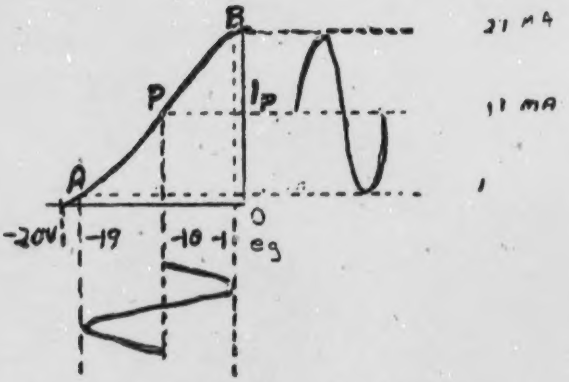


Fig. 2. Amplifier e_g-i_p characteristics.

Any voltage greater than 20 volts peak to peak will cause the tube to cutoff during that part of the negative alternation which drives the grid-to-cathode voltage beyond -20 volts. Therefore, for class A amplification the maximum signal that the amplifier can handle is 20 volts peak to peak. However, the distortionless operation the signal voltage must be limited within the points A and B, that is, 18 volts peak to peak.

Therefore, for class A amplification the operating point is set in the middle of the linear portion of the amplifier's dynamic e_g-i_p characteristic. Moreover, the signal swing is limited to the extreme points A and B of the linear portion.

The equivalent circuit of a triode amplifier (Fig. 3) shows a generator applying a signal voltage ue_g to the plate resistance r_p of the tube in series with the plate load resistor R_L. Of course, e_g is the signal voltage applied to the grid, and u is the amplification factor of the tube. The output voltage e_o is taken across R_L and by voltage-divider action is equal to

$$e_o = \frac{R_L}{r_p + R_L} \times u\, e_g \qquad (1)$$

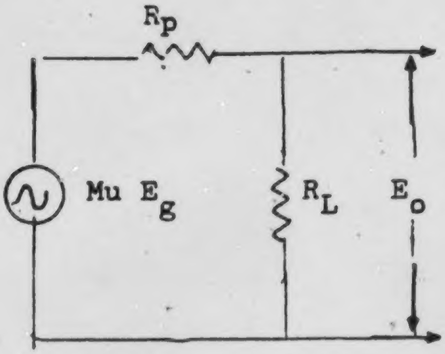


Fig.3. Equivalent circuit of triode amplifier

It is apparent that the gain of the tube, which is determined by comparing e_o with e_{in}, may be found by substituting the formula value of e_o in the equation.

$$\text{Gain} = \frac{e_o}{e_{in}} \qquad (2)$$

This then becomes

$$\text{Gain} = \frac{R_L/(r_p + R_L)}{e_g} \times u\, e_g = \frac{R_L}{r_p + R_L} \qquad (3)$$

It would appear from formula (3) that R_L must be large compared to r_p for efficient operation. However, the size of R_L is limited by the fact that an increased R_L causes the plate-to-cathode voltage of the tube to decrease. The tube then cannot handle as large a signal voltage without distortion.

Formula (3) also shows that the higher the voltage of the tube, the greater is the stage gain possible with proper circuit arrangement.

2. Audio Voltage Amplifiers

Sound waves are transformed into electrical voltages by a microphone. These are called "audio-signal" voltages. The audible frequency range of these audio signals is approximately 20 to 16,000 cps., depending on the source of sound. Audio-signal voltages consist of sine waves in unique frequency combinations within the range of audio frequencies.

The audio voltage amplifier is therefore a special application of the A-C voltage amplifier in Fig. 1. Audio voltage amplifiers use triodes or pentodes and are usually operated class A.

3. Coupling of A-C Signals

Alternating-current signals are frequently coupled capacitively to amplifiers. Consider again the circuit of Fig. 1. The signal voltage e_{in} is applied across the series combination of C and R_g (Fig. 4). The input signal voltage that the grid "sees" is e_g, which is the voltage across R_g. It is apparent that C and R_g form an A-C voltage divider and that e_g is smaller than e_{in}, the signal source, because part of e_{in} is "lost" across C.

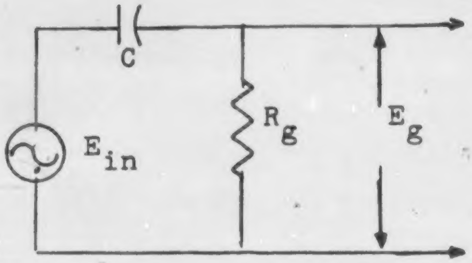


Fig. 4. RC coupling

The voltage e_g depends on the resistance of R_g and the reactance of C and is given by

$$e_g = e_{in} \times \frac{R_g}{\sqrt{R_g^2 + X_C^2}} \qquad (4)$$

X_C depends on the frequency of the signal voltage and on the capacitance of C. For low-frequency audio signals, the reactance of a given capacitor C is higher than the reactance of C at higher audio frequencies.

The "response" of the RC coupling circuit therefore varies for frequencies in the audio range because of the X_C of the capacitor C.

4. Alternating-Current Plate Load

Consider the circuit of Fig. 5. V_1 is an audio amplifier. The audio signal is coupled to the grid of V_1 by C_1 and R_1. This grid signal e_g is amplified by the tube and appears in the plate circuit as e_p This is then coupled by C_2 and R_2 to the grid of the succeeding amplifier V_2.

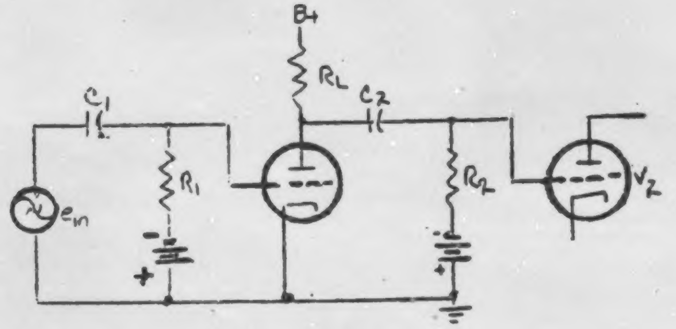
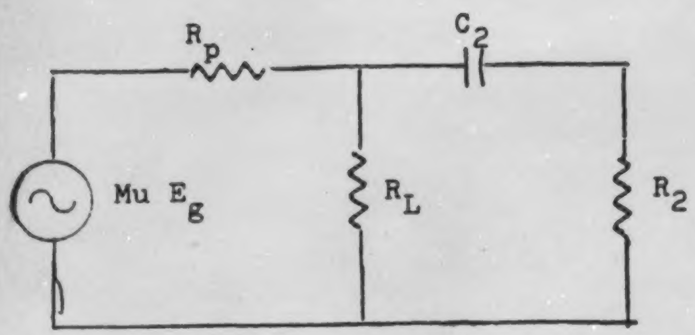


Fig. 5. RC-coupled a-c amplifiers.

The A-C equivalent circuit of V_1 must now include R_L in parallel with the series combination of C_2 and R_2 (Fig. 6). R_L is the D-C plate load. The A-C plate load Z_L consists of the combination of R_L in parallel with the impedance Z_2 of the branch C_2R_2.

If Z_2 is 10 (or more) times greater than R_L, then the A-C and D-C plate loads are effectively the same, namely, R_L. Hence only R_L need be considered in determining the gain of the tube. However, if Z_2 is less than 10 x R_L, the A-C plate load Z_L must be considered in computing the gain of the tube (see Fig. 7). In this case Z_L is necessarily less than R_L and the gain of the tube will be less than when R_L alone was considered.



Equivalent circuit of V_2 a-c plate load
Fig. 6.

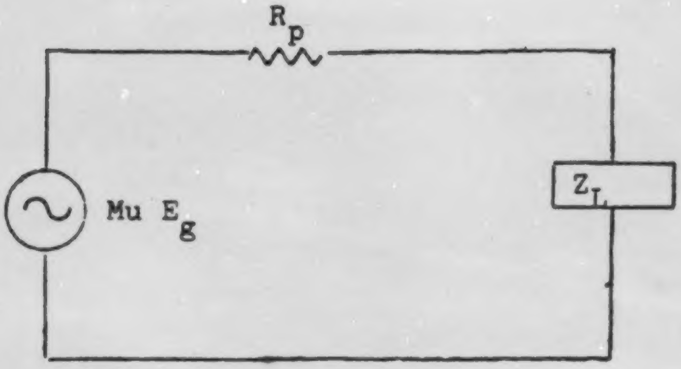


Fig. 7. Alternating--current plate load

Procedure:

1. Connect the circuit of Fig. 8. The triode section of a 6SQ7 is used. Initial value of R_L is 10,000-ohms. Filament pins 7 and 8 are connected to a 6.3-volt rms source. Set variable bias supply E_c so that grid bias is -1 volt. Maintain this bias throughout the experiment.

   Set B+ at 100 volts and maintain it at this value throughout the experiment.

2. Observe with an oscilloscope and adjust the signal-voltage control so that e_g measured from grid to cathode is 1/2 volt peak to peak.
3. With a scope observe and measure the output-signal voltage e_p at the plate of the amplifier. Record in Table 1.
4. Measure and record in Table 1 the D-C voltage at the plate, pin 6.
5. Repeat steps 1 through 4 for each value of R_L in Table 1 and record results.

TABLE 1

R_L, ohms	e_g, volts peak to peak	e_p, volts peak to peak	Plate voltage D-C
10,000	1/2		
100,000	1/2		
270,000	1/2		
470,000	1/2		
1 Meg	1/2		
4.7 Meg	1.2		

6. From the relationship

$$\text{Gain} = \frac{e_o}{e_{in}} = \frac{e_p}{e_g}$$

Compute amplifier gain for each of the plate loads and record in Table 2.

7. Using the formula

$$\text{Gain} = \frac{u R_L}{R_L + r_p}$$

compute amplifier gain for each of the plate loads and record in Table 2.

8. Repeat steps 1 and 2 for R_L = 270,000 ohms.

9. With a scope observe the output signal voltage e_p at the plate of the amplifier.

10. Vary the bias supply voltage E_c from 0 to -10 volts.

    (a) Note, measure, and record the range of bias over which there is no distortion of signal voltage e_p.

    (b) What is the effect on e_p when the bias is not within the range noted in Step 10a?

TABLE 2

R_L, ohms	Gain = e_p/e_g	Gain = $uR_L/(R_L+r_p)$
10,000		
100,000		
270,000		
470,000		
1 Meg		
4.7 Meg		

11. Reset the bias at -1 volt. Vary the signal voltage e_g from 0 to maximum.

    (a) Note, measure, and record the signal-voltage range over which there is no distortion of signal voltage e_p.

    (b) What is the effect on e_p when e_g is not within the range noted in Step 11a?

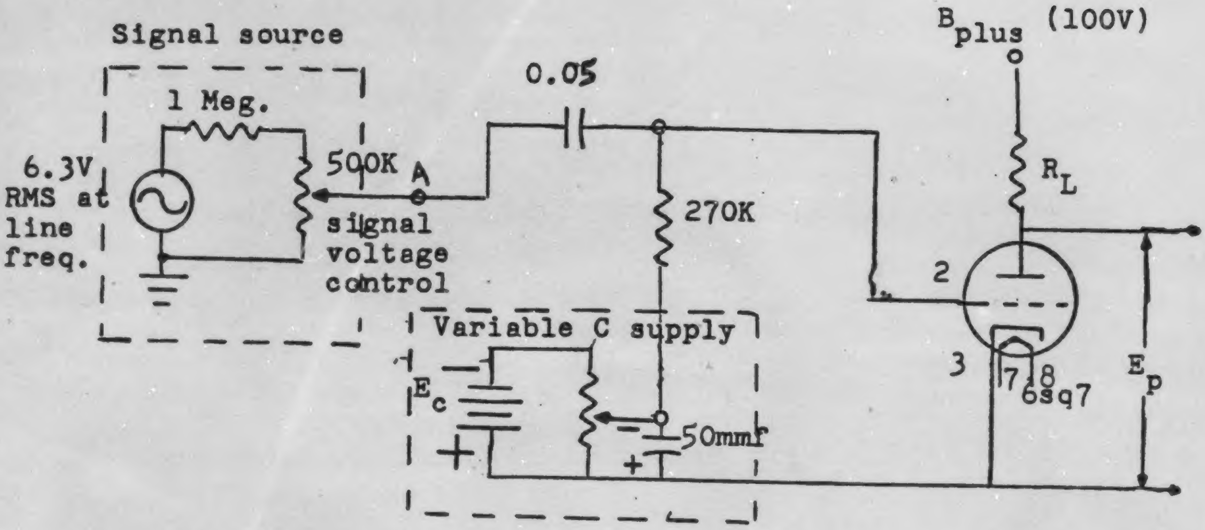

Signal source
1 Meg.
6.3V RMS at line freq.
500K
A
signal voltage control
0.05
270K
Variable C supply
E_c
50mmf
B_{plus} (100V)
R_L
2
3
7
8
6sq7
E_p

Fig. 8 Circuit for determining gain of audio amplifier

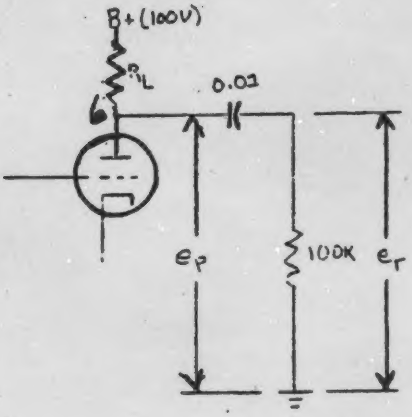

B+(100V)
R_L
0.01
6
e_p
100K
e_r

Fig. 9. RC-coupling network.

12. To the circuit of Fig. 8 add an RC coupling network as in Fig. 9. Initial value of R_L is 10,000 ohms.

13.. Set grid bias at -1 volt and e_g = 1/2 volt peak to peak.

14. With an oscilloscope observe, measure, and record in Table 3 e_p and e_r.

15. Measure and record the D-C voltage at the plate.

16. Repeat steps 13, 14, and 15 for every value of R_L in Table 3.

17. Compute the gain (e_p/e_g) of the amplifier for each value of R_L and record in Table 3.

TABLE 3

R_L, ohms	e_g, volts peak to peak	e_p, volts peak to peak	e_r, volts peak to peak	Plate voltage D-C	Gain e_p/e_g
10,000	1/2				
100,000	1/2				
270,000	1/2				
470,000	1/2				
1 Meg	1/2				
4.7 Meg	1/2				

18. Disconnect the circuit of Figs. 8 and 9 and replace it with the circuit of Fig. 10. A 6J5 is used. Connect the output of a phonograph pickup or other audio source across the signal-voltage control (volume control). Set grid bias at -3 volts approximately and B+ at approximately +100 volts.

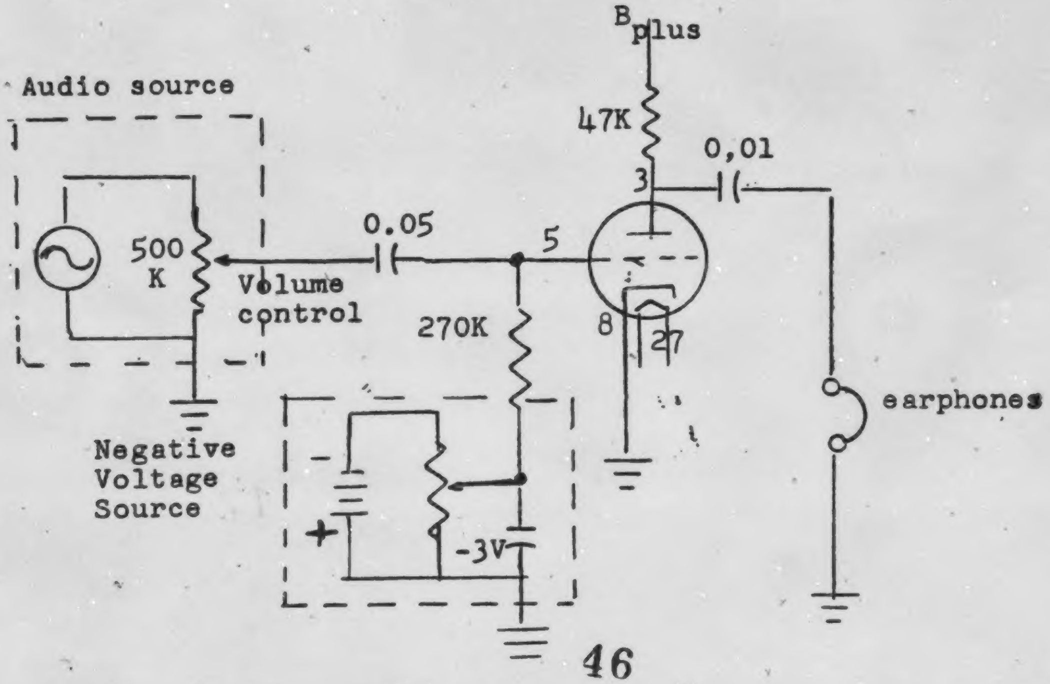

B plus
47K
0,01
3
Audio source
0.05
5
500 K
Volume control
270K
8
2
7
earphones
Negative Voltage Source
-
+
-3V

Fig. 10. Connecting earphones to an audio amplifier

19. High-impedance earphones are connected as shown and form part of the A-C load.

20. Adjust volume control for normal sound and indicate quality of the reproduced sound.

21. Connect an oscilloscope to the plate of the amplifier. Observe and record the audio signal. Note effect of loud and weak sound on amplitude of the audio signal voltage.

Questions:

1. What is a class A amplifier?
2. Why should an audio voltage amplifier operate class A?
3. a. What does an audio signal consist of?
   b. Draw the audio signal voltage that you observed on the scope.
   c. What effect did the loudness of sound have on the amplitude of the audio signal voltage?
4. a. What effect does the plate load resistor R_L have on the gain of an audio amplifier?
   b. What limitation did you find on the size of R_L (refer to data of Table 1)?
5. What is meant by the A-C plate load?
6. For what values of R_L was the gain of the amplifier in Fig. 8 appreciably different from the gain of the amplifier in Fig. 7? Explain.
7. Compare the values of e_R and e_p in Table 3 and explain the difference, if any, in these voltages.
8. How does a volume control function?
9. Why are high-impedance earphones used in this job?

CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

Job Sheet 8B
Page 1 of 8

Bias in Amplifiers

Objectives:

1. To study the operation of cathode or self-bias in an amplifier.
2. To verify that the cathode resistor R_K used to provide self-bias must be properly bypassed to avoid degeneration.
3. To determine the value of R_K in a specific circuit.

Materials Required:

Power Supply:	Variable + direct current, 6.3 volts rms
Equipment:	Oscilloscope, VTVM, VOM
Resistors:	1/2 watt, 4,700-ohm, two 270,000-ohm, 470,000-ohm, 1 meg.
Capacitors:	0.05-uf, 0.1-uf, 50-uf 25 volts
Tubes:	6SQ7
Miscellaneous:	10,000-ohm and 500,000-ohm pots

Introductory Information:

1. Cathode Bias

In the early days of radio C batteries were used to provide bias for amplifier circuits. These C batteries were soon eliminated by a circuit arrangement which provided bias without any external bias-voltage source. The circuit arrangement utilizes normal electron flow in the tube to provide "self"-bias. Consider the circuit of Fig. 1. When power is applied, there is electron flow through the tube in the direction indicated by the arrows. There is a voltage drop E_K across R_K, with polarity shown, as a result of this electron flow. E_K may be measured from K to ground, with a D.C. voltmeter. In the grid circuit of this tube, there is no direct current. Direct-current voltage measured from grid to ground (E_g) is therefore zero, or g is at ground potential. The cathode K is positive with respect to the grid. If, in Fig. 1, E_K = +2 volts, then K is 2 volts positive with respect to the grid. Another way of saying this is that the grid is 2 volts negative with respect to the cathode. Measurement will in this case show that the grid is 2 volts negative with respect to cathode.

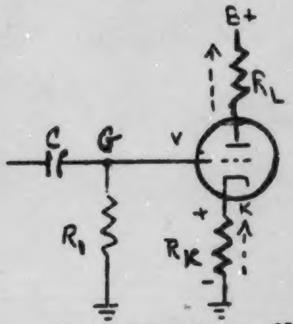


Fig. Electron flow in tube.

Bias was previously defined as grid-to-cathode voltage. Here then is another means of biasing the tube, namely, by cathode or self-bias.

The value of voltage E_K at the cathode with respect to ground depends on the size of R_K and on the value of the current in the cathode circuit. In the triode circuit of Fig. 40-1, there is no grid current. Hence cathode current and plate current are the same. Assume that there is 1 ma of plate current. The size of R_K which will give 2 volts bias (i.e. $E_K = +2$ volts) can now easily be found. From Ohn's Law,

$$R_K = \frac{E_K}{I} \qquad (1)$$

Substituting $I = 0.001$, $E_K = +2$, in formula (1), we have

$$R_K = 2{,}000 \text{ ohms} \qquad (2)$$

The above method for finding the value of R_K for a specified bias requires the value of cathode current to be known for the conditions of operation of that tube. From the family of plate characteristics of a tube, it is possible to find the value of plate current by use of a load line. The load line is a straight line which is drawn on the graph of plate characteristics of a tube. To draw a load line, it is necessary to know

1. The B+ supply available for plate voltage.
2. The plate-load resistor R_L.
3. The tube characteristics.

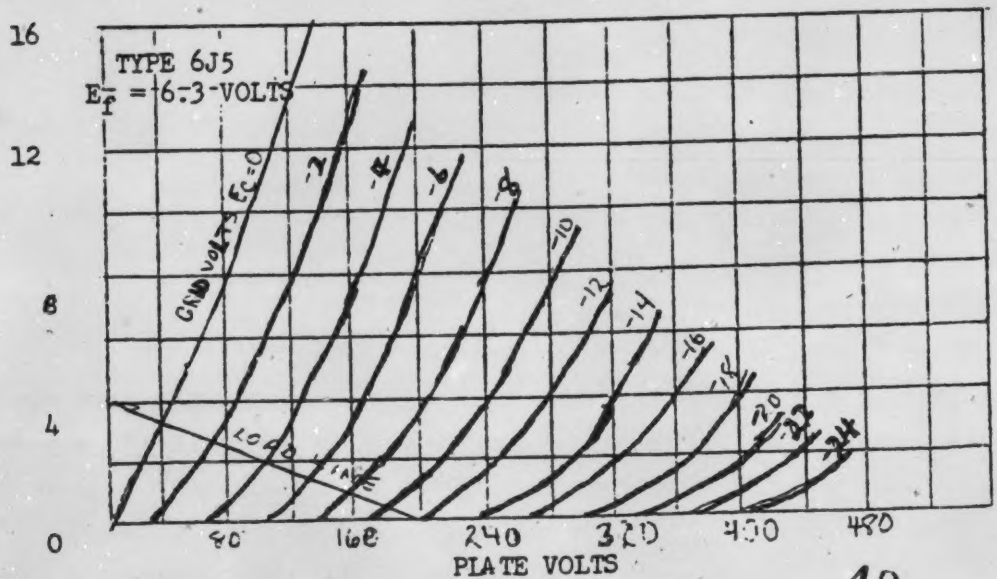

AVERAGE PLATE CHARACTERISTICS

Fig. 2. Drawing the load line.

Consider Fig. 2. This is the family of characteristics for the 6J5. Suppose it is required to operate this tube at -2 volt bias, using a plate load resistor $R_L = 50{,}000$ ohms and a B+ supply voltage of 200 volts. Two points which determine this load line are

1. The 200-volt point (B+ supply) on the "plate volts" (horizontal) axis.
2. The 4-ma point on the "plate milliamperes" (vertical) axis. This point is obtained by dividing the B+ supply voltage by the plate load resistor. In this case we have $I = 200/50{,}000 = 4/1{,}000$, or 4 ma.

Now to determine how much current will flow through the tube with a 50,000-ohm load at -2 volt bias, find the intersection of the 50,000-ohm load line with the plate characteristic curve at -2-volt bias. In this case, it is 2.7 ma.

The required facts (plate current and bias) are now known, and it is possible to find R_K, which is

$$R_K = \frac{4}{0.0027} = 1{,}480 \text{ ohms.}$$

Thus a 1,500-ohm resistor would be used.

Tube manuals publish charts showing the proper values of R_K and R_L with specified B+ supply voltages for RC-coupled class A amplifiers.

2. The Cathode Bypass Capacitor

In the circuit (Fig. 1) the cathode resistor R_K acts to reduce the gain of the amplifier by providing degeneration, or negative feedback. Consider the effect of a sine-wave signal voltage applied between grid and ground. On the positive alternations, plate current (hence cathode current) increases, On the negative alternations, plate current decreases. This causes the cathode voltage to vary in phase with grid voltage and a sine-wave signal voltage now appears in the cathode, which "follows" the grid voltage. The signal voltage which the tube "sees" is the effective grid-to-cathode voltage. Therefore, to determine the effective signal voltage to tube, it is necessary to subtract the cathode signal voltage from the grid signal voltage. Thus the tube "sees" a smaller amplitude signal e_g than was injected. Obviously, the output signal at the plate, e_p, is smaller than it would be if E_K did not vary with the input signal.

It is therefore necessary to maintain a constant bias voltage at the cathode, despite grid-signal variations, if cathode bias is to be effective. This can be accomplished by "bypassing" R_K with a suitable capacitor C_K as in Fig. 3. C_K provides another path for alternating current in the cathode circuit. Thus cathode-current variations can flow through R_K and C_K, and the distribution of current between R_K and C_K will depend on the X_C of C_K as compared with R_K.. Thus, if X_{CK} = 200 ohms and R_K = 2,000 ohms, 10/11 of the alternating current will flow through C_K and only 1/11 through R_K. Bypassing R_K with C_K, in this instance, reduces the effects of degeneration. However, it does not affect the direct current through R_K. Therefore, E_K, the cathode-bias voltage, is maintained at its required value.

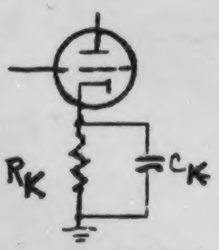


Fig. 3. Cathode bypass capacitor.

If an amplifier is required to handle more than one frequency, then the value of C_K must be chosen so that it provides adequate bypassing for the lowest of all the frequencies. It will then be a good bypass for all the higher frequencies also.

To determine the size of C_K, it is therefore necessary to know the lowest frequency F_0 it is required to bypass the size of the cathode resistor R_K in parallel with it. C_K is considered a good bypass if at F_0

$$X_{CK} = \frac{R_K}{10}$$

The procedure which follows requires that low D-C voltage readings be made in cathode circuits and in high-impedance grid circuits. The input impedance of a VTVM is sufficiently high that circuit loading is negligible. The ground lead of the VTVM, however, may disturb a circuit if placed at a high-impedance test point. Thus, when you read a voltage between grid and cathode, it is best to place the VTVM ground lead to chassis ground, read the grid voltage, read the cathode voltage, and compute the total cathode-to-grid voltage. If the grid circuit happened to be open, however, unreliable indications might be obtained. Therefore, a voltage reading between grid and cathode would be advisable with the VTVM ground lead connected to the lower-impedance point, usually the cathode.

A VOM with a low input impedance might disturb a circuit sufficiently to cause erroneous readings. Assume a 1,000-Ohms-per-volt VOM is set on the 10 volt range. This means the circuit under test becomes loaded by 10,000 ohms, the VOM input impedance. If the VOM is placed across a 5,000-ohm cathode resistor, the total cathode-circuit resistance becomes 3,300 ohms. If, on the other hand, the VOM is placed from cathode to grid (Fig. 4a), it creates a voltage divider across the voltage source E_K, which gives an erroneous bias reading. Thus the equivalent circuit (Fig. 4b) shows that with a large R_g and a small R_M the voltage across R_M, grid-to-cathode voltage, is small compared with E_K. In addition to the above effect, the voltage E_K will also change because of the change in grid bias, when a meter with a low ohms-per-volt characteristic is used to read grid bias in a high-impedance circuit.

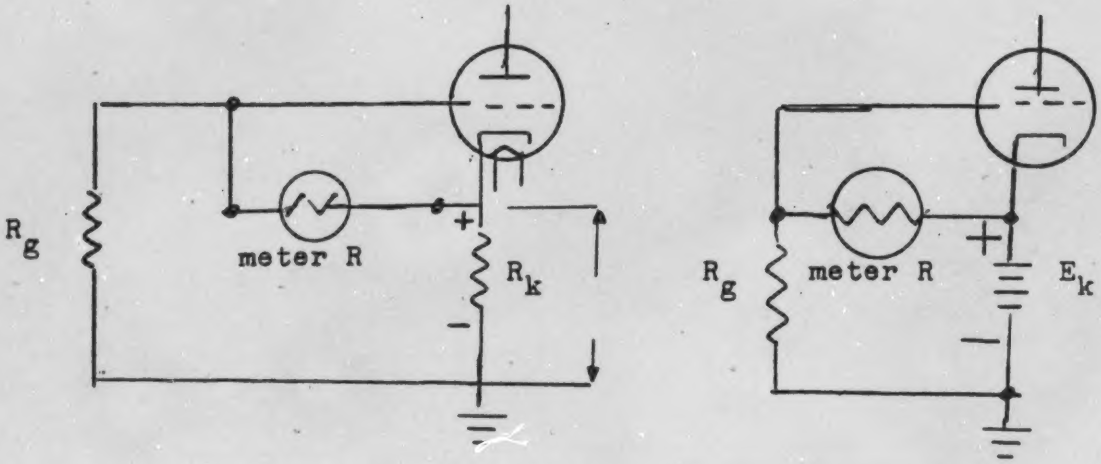


Fig. 4. VOM loading

Procedure:

1. Connect the circuit of Fig. 5. The filaments of the 6SQ7 are connected to a 6.3-volt source. B+ is adjusted for +200 volts. C_K is a 50-uf 25-volt capacitor. Observe polarity in connecting C_K.

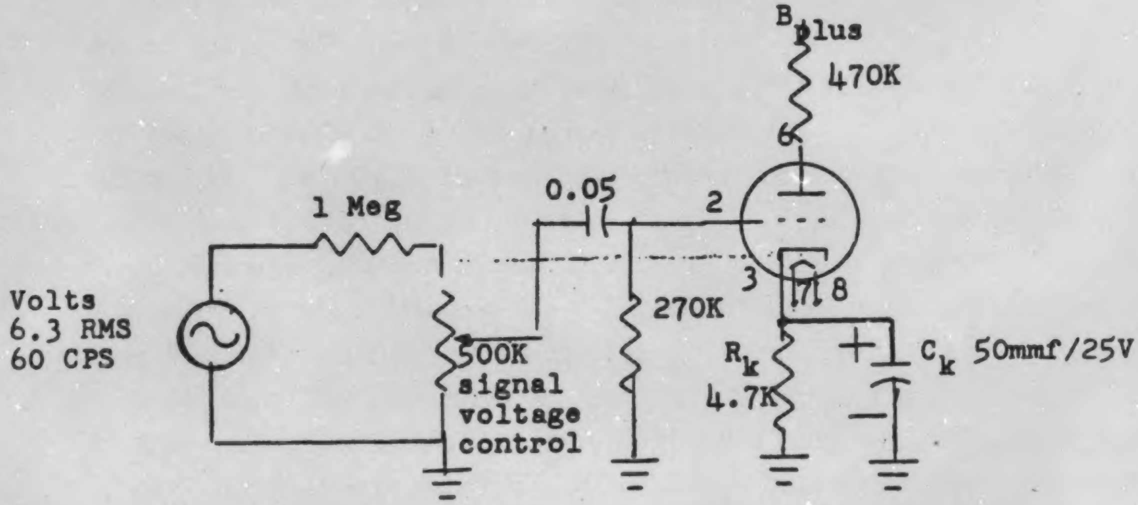

B plus
470K
6
0.05
2
1 Meg
3
8
Volts
6.3 RMS
60 CPS
270K
500K
signal
voltage
control
R_k
4.7K
+
C_k 50mmf/25V
−

Fig. 5. Circuit for determining effects of cathode bypass capacitor

2. Adjust signal-voltage control so that e_g, signal voltage in the grid, equals 1/2 volt peak to peak.

3. Measure the D-C voltage at the plate, grid, and cathode with respect to ground and record in Table 1.

TABLE 1 (R_L = 470,000 ohms)

C_K, uf	D-C voltage with respect to ground			Bias	e_p, volts peak to peak	e_K, volts peak to peak	Gain e_p/e_g
	E_g	E_K	E_p				
50							
0.1							
0							

4. Measure the bias (grid-to-cathode) voltage using a VTVM and record in Table 1.

5. Observe and measure with an oscilloscope and record in Table 1 the signal voltage e_p at the plate and e_k at the cathode.

6. Power Off. Remove C_K and replace it with a 0.1-uf capacitor.

7. Power On. Repeat Steps 2 through 5 and record results in Table 1.

8. Power Off. Remove C_K and leave R_K unbypassed.

9. Power On. Repeat Steps 2 through 5 and record results in Table 1.

10. Power Off. Compute the gain of the amplifier for every value of C_K and record in Table 1.

11. Compute the size R_K which will be required to give 1-volt bias to the circuit of Fig. 5 if R_L is 270,000 ohms and B+ 200 volts. (Use load line on 6SQ7 plate characteristics).

12. Connect the circuit of Fig. 5 using the value of R_K just determined; R_L = 270,000 ohms, C_K = 50-uf, 25 volts.

13. Power On. Measure and record the D-C voltage at the cathode with respect to ground.

14. If E_K does not equal 1 volt, determine experimentally the value of R_K required to give 1 volt. Use a 10,000-ohm rheostat in the cathode circuit as R_K and adjust it so that E_K = 1 volt. Now remove the rheostat from the circuit and measure and record its resistance R_K.

15. Connect the resistor R_K of Step 14 in the cathode circuit and repeat Steps 2 through 10. Record in Table 2.

TABLE 2 (R_L = 270,000 ohms)

C_K, uf	D-C voltage with respect to ground			Bias	e_p volts peak to peak	e_K volts peak to peak	Gain, e_p/e_g
	E_g	E_K	E_p				
50							
0.1							
0							

16. Connect the 50-uf capacitor and VTVM across R_K.

17. Turn power ON and read and record cathode voltage on VTVM.

18. With the VOM read and record grid-to-cathode voltage and read and record the new cathode voltage on the VTVM.

Questions:

1. What happens to the signal voltage e_p as C_K is changed from 50 to 0.1 uf? Refer to data in Tables 1 and 2. Explain.

2. Does the signal voltage e_K in the cathode change as C_K is changed? Why?

3. Does the D-C voltage E_K in the cathode change as C_K is changed? Why?

4. How does the gain of the 6SQ7, using R_L = 270,000 ohms and 1-volt self-bias, compare with the gain of the 6SQ7, using R_L = 270,000 ohms and 1-volt fixed bias (see Job 8A)? Explain any difference.

5. Explain how you could determine the proper size of cathode resistor to use for a 6SQ7 having a plate load R_L = 1 Meg and B+ source of 180 volts, requiring a bias of -1/2 volt.

6. Compute the value of cathode capacitance required to bypass a 10,000-cps signal if R_K = 5,000 ohms. Show all work.

7. From Table 1, compute the effective signal voltage from grid to cathode of the amplifier using the unbypassed cathode. With this effective signal input, compute the gain of the stage. Compare with gain obtained with 50-uf bypass capacitor.

8. Describe the effect of the 0.1-uf cathode bypass capacitor. Explain.

9. Compute current from the voltage drop across plate load and cathode resistor. Compare.

10. Explain the results obtained in the procedure Step 18. What conclusions can be drawn regarding reading grid-to-cathode voltages, using a VOM in a high-impedance circuit?

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BASIC ELECTRONICS

Job Sheet 9
Page 1 of 6

Characteristics of Amplifiers

Objectives:

1. To observe the 180° phase shift between the signal on the grid and plate of a class A amplifier operating with a resistive plate load.
2. To study the operation of a phase inverter.

Materials Required:

Power Supply:	Variable + direct current, 6.2 volts rms
Equipment:	Oscilloscope and VTVM or VOM
Resistors:	1/2 watt, three 47,000-ohm, two 100,000-ohm, 1-Meg; 1.5-Meg. 1,000-ohm.
Capacitors:	0.05-uf; 50-uf, 25 volts.

Introductory Information:

1. Phase Relationships in an Amplifier

In following a signal voltage through an amplifier, the technician should understand the phase relationship between the signal voltage at the grid and at the plate. This phase relationship can be readily understood by observing the effects on the plate voltage when the grid voltage is varied in the amplifier (Fig. 1). Suppose that the plate characteristics of this tube without signal are such that there is a 3-ma plate current when the grid is biased at -3 volts. The resultant voltage drop across R_L is 30 volts, and the plate voltage E_p is therefore 70 volts (70 volts = 100 - 30 volts). Assume further that there is a 1-ma change of I_p for every 1-volt change of bias. When E_c is adjusted so that the bias is -4 volts, there will be only 2 ma of plate current. Hence the voltage drop across R_L is only 20 volts and E_p will go up to 80 volts. That is, as the grid is driven more negative, (changed from -3 to -4 volts), the plate voltage becomes more positive (changed from +70 to +80 volts).

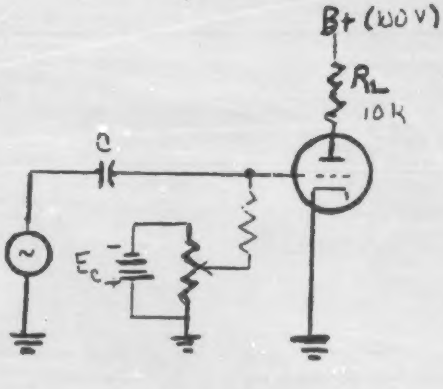


Fig. 1. Voltage Amplifier

Similarly, if the bias is varied from -3 to -2 volts, plate current will increase from 3 to 4 ma. Hence the voltage drop across R_L will be 40 volts and the plate voltage E_p will be 60 volts. That is, as the grid is driven more positive (changed from -3 to -2 volts), the plate voltage drops or becomes more negative (changed from +70 to +60 volts).

This relationship can be stated as follows: In a class A amplifier with a resistive plate load, there is a 180° phase difference between a voltage change at the grid and the resulting voltage change at the plate. That is, as the grid voltage goes up (becomes more positive), the plate voltage goes down, and as the grid voltage goes down (b-comes more negative), the plate voltage goes up.

The signal voltage that an amplifier "sees" is the grid to cathode voltage. In most applications the cathode is bypassed and there is no A-C variation in voltage at the cathode. However, it is possible to leave the cathode unbypassed, a signal voltage appears across the cathode resistor which reduces amplifier gain through degeneration.

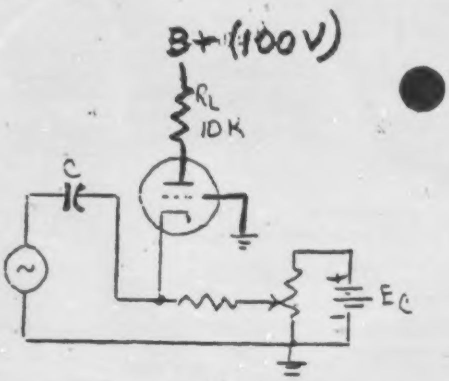


Fig.2. Amplifier with signal input to cathode

What is the effect on plate voltage of introducing a signal voltage into the cathode? Consider the circuit of Fig. 2. Assume the same tube as in Fig. 1, with the grid now grounded (zero D-C potential with respect to ground) and the cathode connected to a variable source of positive D-C voltage. When the cathode voltage E_K is +3 volts, the bias is -3 volts (grid voltage measured with respect to cathode). Therefore, a positive voltage on the cathode has the same effect on plate-current flow as a negative voltage on the grid. Similarly, a negative voltage on the cathode has the same effect as a positive voltage on the grid.

It is now possible to summarize the conclusions on phase relationships in an amplifier with resistive plate load to include the cathode. That is, the voltage at the cathode plate are phase. The voltage at the grid and plate are 180° out of phase.

Now consider the effect of introducing an A-C signal voltage into the grid of the amplifier in Fig. 1. Observation of the signal waveforms at the grid and plate (Fig. 3) would show that the signal at the plate has been amplified but is 180° out of phase with the signal voltage at the grid.

Similarly, Fig. 4 shows that if a signal is introduced into the cathode of Fig. 2, the signal voltages at the cathode and plate are in phase.

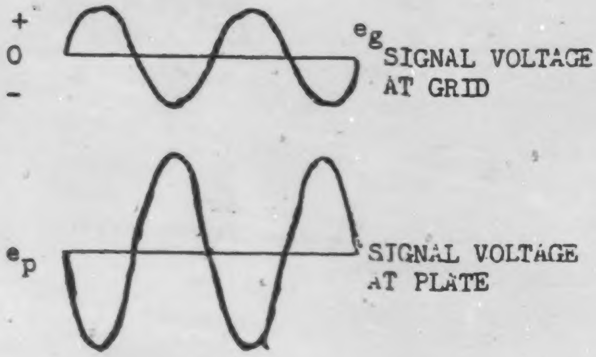


Fig.3 Phase relationships between grid and plate in amplifier

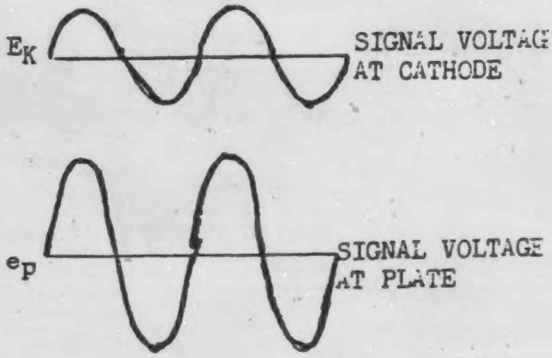


Fig. 4. Phase relationships between cathode and plate in amplifier.

2. The Phase Inverter

The audio signals fed to the control grids of a push-pull amplifier must be equal in amplitude but 180° of phase. One way of accomplishing this effect is by the use of a phase inverter.

An amplifier with resistive plate load and unity (1) gain can be used as a phase inverter. For example, assume that two signal voltages each 20 volts peak to peak and 180° out of phase are required and that e_{p1} (Fig. 5) represents one of these signals. If this signal is coupled to the grid of a class A amplifier V_2 (Fig. 6) with resistive plate load, there will be a signal voltage (e_{p2}) at the plate of V_2 which is 180° out of phase with the input. However, e_{p2} will be greater than e_{p1} by a factor equal to the gain (G) of V_2. That is,

$$e_{p2} = G \times e_{p1} \qquad (1)$$

Thus, if the gain of V_2 is 4, then e_{p2} will be 80 volts peak to peak, or four times as large as that of e_{p1}: The requirements are for a signal voltage 180° out of phase with e_{p1} but of equal amplitude (20 volts peak to peak).

A simple method for reducing the amplitude of e_{p2} is to feed only 1/4 of e_{p1} to the grid of V_2. This can be accomplished by a resistive divider network, as in Fig. 6. The signal voltage e_{p1} is coupled by C, R_1, and R_2 to the grid of V_2.

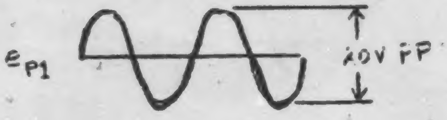


Fig. 5. Sine-wave signal voltage.

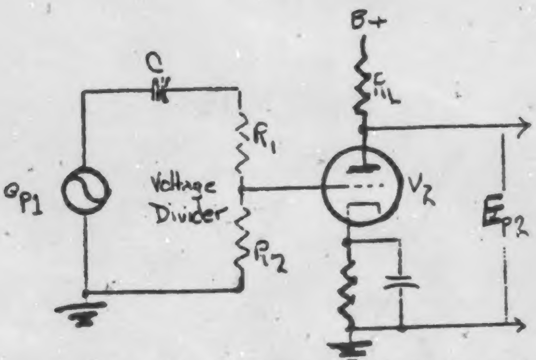

B+
C
R_L
R_1
e_{P1}
Voltage Divider
V_2
R_2
E_{P2}

Fig. 6. Voltage divider for phase inverter.

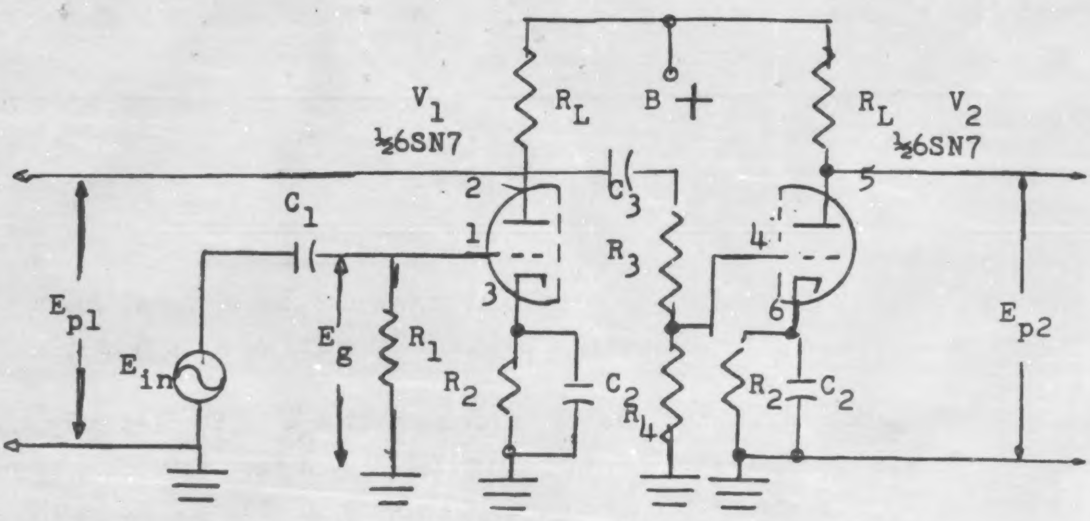
The values of R_1 and R_2 are chosen so that

$$\frac{R_2}{R_1 + R_2} = \frac{1}{G} = \frac{1}{4} \qquad (2)$$

Therefore only 1/4 of e_{p1} is coupled to V_2. Since the gain of V_2 was assumed to be 4, then

$$e_{p2} = 4\,(1/4\ e_{p1}) = e_{p1} \qquad (3)$$

The signal voltages e_{p1} and e_{p2} are now equal to amplitude and 180° out of phase as required, V_2 is the phase inverter.


V_1
½6SN7
R_L
B +
R_L
V_2
½6SN7
2
C_1
1
3
C_3
R_3
4
5
6
E_{p1}
E_{in}
E_g
R_1
R_2
C_2
R_4
R_2
C_2
E_{p2}

Fif. 7. Practical phase-inverter

The circuit of Fig. 7 shows a practical application of a phase inverter. V_1 is an audio voltage amplifier which amplifies an input signal e_g. The output of V_1 is e_{p1} and is taken from the plate circuit. V_2 is the phase inverter. By proper divider ratio, $R_4/(R_3 + R_4)$, the signal voltage e_{p1} is reduced to e_g and this is coupled to the grid of V_2. V_2 and V_1 are connected as symmetrical amplifiers with the same gain. Hence the signal voltage e_{p2} at the plate of V_2 is equal to e_{p1} but 180° out of phase.

The ratio is

$$\frac{R_4}{R_3 + R_4} = \frac{1}{G} \qquad (4)$$

where G is the gain of V_2.

There are other types of phase inverters.

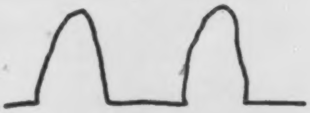


Fig. 8. Clipped sine wave

In this job you will experimentally verify the phase relationships in an amplifier. To follow the phase changes easily, a nonsymmetrical input signal voltage will be used, such as the output of a diode limiter (seeFig. 8).

Procedure:

1. Connect the circuit of Fig. 9. The input-signal source is a 6.3 volt rms line-frequency A-C voltage. The filaments of the 6H6 and 6SN7 are connected to the 6.3 volt filament source. The 6H6 is used to limit the negative portion of the input signal.

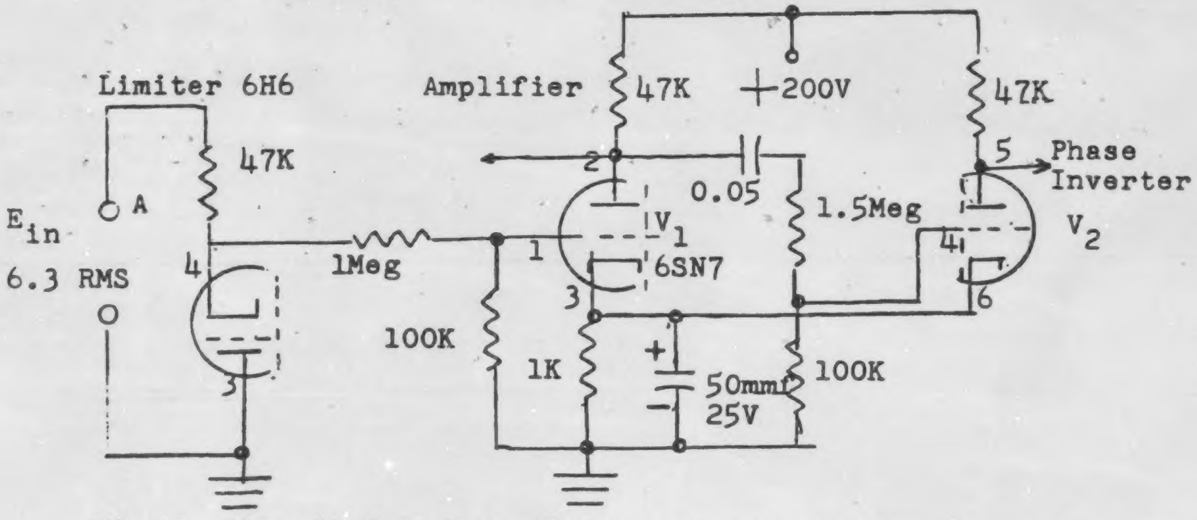
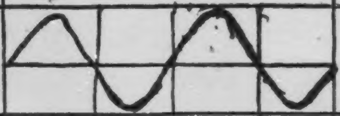


Fig.9. Circuit for determining characteristics of a phase inverter

2. With an oscilloscope observe the signal waveform and measure and record the peak-to-peak voltage at every point shown in Table 1. All measurements are made with respect to ground.

   Draw 2 cycles of signal voltage and show proper phase relationship with respect to the input sine wave shown at point A in Table 1.

TABLE 1

Tube	Pin No.	Signal waveform	Peak-to-peak volts	D-C volts	Resistance
	Point A				
6H6	4				
6SN7	1				
	2				
	4				
	5				
	3-6				

3. Measure and record the D-C voltage at every point shown in Table 1.
4. Power Off. Measure resistance with respect to ground and record in Table I, at every point shown.
5. Compute and record the gain of V_1 and V_2.
6. Compute and record the divider ratio of the phase-inverter input grid.

Questions:

1. State in your own words the phase relationships between signal voltages on the grid and plate in a class A amplifier using a resistive plate load. (Refer to data in Table 1).
2. What is a phase inverter?
3. What is the effect of tying the cathodes of V_1 and V_2 together in in Fig. 9?
4. Is there a waveform in the cathode, pin 3 of V_1? Why?
5. Is the cathode bypass capacitor (pins 3 and 6 of 6SN7) necessary in this circuit? Explain.
6. Explain the operation of the 6H6 in the circuit of Fig. 9.
7. How do e_{p1} and e_{p2}, the signal voltages on pins 1 and 4 of the 6SN7, compare in amplitude and phase in the circuit of Fig. 9? Why?

CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

Job Sheet 10
Page 1 of 4

Push-Pull Amplifier

Objective:

To study the characteristics of a push-pull amplifier.

Materials Required:

Power supply:	Variable + direct current, 6.3 volts rms
Equipment:	Oscilloscope, VTVM
Resistors:	1/2 watt, 1,000-ohm; 33,000-ohm; three 47,000-ohm; two 470,000-ohm; 1-Meg; 2 watts, 470-ohm; 4 watts, 5-ohm.
Capacitors:	Two 0.05-uf; 50-uf, 25 volts
Tubes:	6SN7, two 6K6
Miscellaneous:	Push-pull output transformer properly matched.

Introductory Information:

It is frequently necessary to have more audio power than that which a single output tube can provide. One solution to this problem is to use two or more output tubes in parallel. Another solution is to connect them in push-pull.

In the circuit of Fig. 1, V_1 and V_2 are two power amplifiers connected in push-pull. The control grids are fed by two separate sources e_{g1} and e_{g2} supplying signals equal in amplitude but 180° out of phase. Thus, when the grid of V_1 is going in a positive direction, the grid of V_2 is going in a negative direction, and vice versa. As a result, when plate current in V_1 is increasing the plate current in V_2 is decreasing.

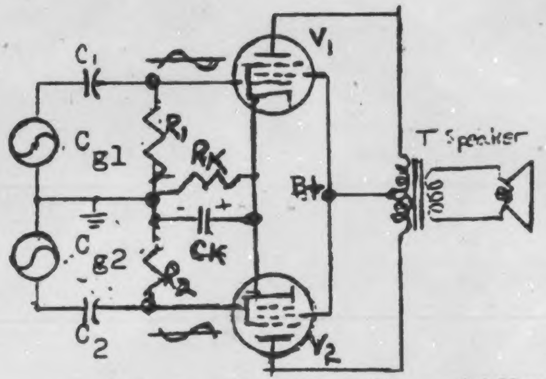


Figure 1. Push-pull amplifier.

The plate currents of V_1 and V_2 flow in opposite directions through the primary of the output transformer. Suppose the magnetic field that the current of V_1 sets up about the primary is expanding when plate current through V_1 is increasing. At this same time, plate current in V_2 is decreasing and the resulting magnetic field is moving in the same direction as the field arising from V_1. Hence the two fields aid and induce a larger emf in the secondary than either could acting alone. The power delivered by two tubes connected in push-pull is greater than that which either could deliver alone.

Push-pull amplifiers may be operated class A, AB, or B. When biased for class AB or class B operation, they can handle a signal amplitude approximately twice as large as that which a conventional class A power amplifier can handle. Distortion caused by even harmonics is inherent in the operation of a power amplifier. Push-pull amplifiers reduce this type of distortion. More residual-hum voltage from the power supply can be tolerated because of the effects of hum cancellation in the plate circuits.

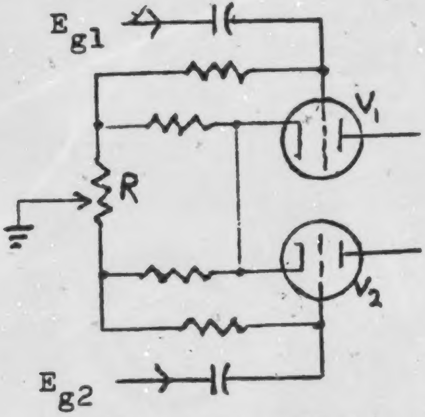


Figure 2. Bias Compensation.

The desirable characteristics of a push-pull amplifier stem from the fact that it is a balanced circuit. Frequently, variable adjustments are included to maintain the two tubes in balance. In Fig. 2, R is used to adjust the bias on V_1 and V_2 to compensate for any change in characteristics of these two tubes.

Procedure:

1. Connect the circuit of Fig. 3. The control grids of the 6K6's are fed by the output of the phase inverter. A 5-ohm 4-watt dummy load resistor is used across the secondary of the output transformer T.

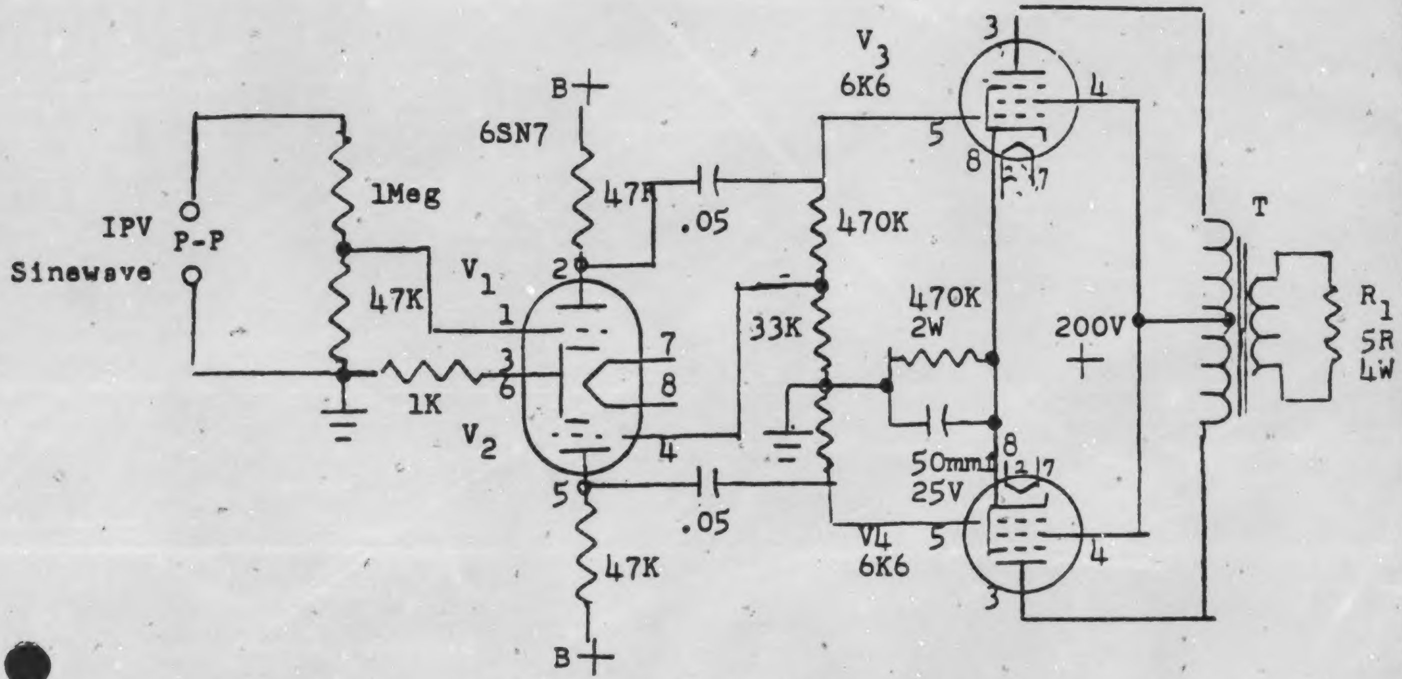

IPV
P-P
Sinewave
1Meg
47K
1K
V1
V2
6SN7
B+
47K
2
1
3
6
7
8
4
5
.05
.05
47K
B+
470K
33K
470K
2W
50mmf
25V
V3
6K6
V4
6K6
3
4
5
8
7
200V
+
T
R1
5R
4W

Fig. 3. Phase inverter and push-pull amplifier

TABLE 1

	Waveform across R_L	Peak-to-peak voltage	6K6, D-C Volts			
			At pin 4	At pin 8	At pin 3 of V_3	At pin 3 of V_4
V_3 and V_4 in						
V_4 only						
V_3 only						

2: With an oscilloscope observe and measure the peak-to-peak voltage across R_L. Measure the D-C voltages on V_3 and V_4 at pins 4 and 8 and at each pin 3. Record in Table 1. All measurements are made with respect to ground. Draw 2 cycles of signal voltage.

3. Remove V_3 (6K6).
4. Repeat Step 2.
5. Replace V_3 and remove V_4.
6. Repeat Step 2.

Questions:

1. State three identifying characteristics of a push-pull output stage.
2. What is the class of operation of tubes V_3 and V_4 in Fig. 3?
3. Would it ever be necessary to "unbalance" the push-pull amplifier of Fig. 3? Explain.
4. What is the effect of removing either output tube of a push-pull amplifier on a. Power delivered to the load? b. Distortion?
5. What class of operation should be used to handle a very large input-signal voltage? Why?
6. Is it always necessary to bypass the common cathode resistor in a push-pull amplifier? Explain.

CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

Job Sheet 11
Page 1 of 4

Characteristics of Amplifiers

Objectives:

To measure the frequency response of an audio amplifier.

Materials Required:

Power Supply:	Variable + direct current, 6.3 volts rms
Equipment:	Oscilloscope, VTVM, audio oscillator
Resistors:	1/2 watt, 2,200-ohm; two 270,000-ohm; 330,000-ohm; 1 watt, 1,000-ohm; 4 watts, 5-ohm.
Capacitors:	Two 0.01-uf, 0.02-uf
Tubes:	6SQ7, 6K6
Miscellaneous:	Audio output transformer

Introductory Information:

The range of sound frequencies that the average person can hear is 30 to 15,000 cps, approximately. An audio amplifier which is designed to reproduce audio signal voltages faithfully should be able to amplify equally signal voltages in this range of frequencies. Frequently, however, because of price and other practical considerations, audio amplifiers do not permit the entire range of audio frequencies to pass equally. In particular, the low frequencies (up to 500 cps) and the high frequencies (beyond 5000 cps) may be attenuated.

An important characteristic of an audio amplifier, then, is the output voltage that it provides at each of the frequencies within the audio range for a given level of input signal. This characteristic can be determined by using an audio oscillator as the signal source and an oscilloscope for observing and measuring the input and output signal. The gain is then computed at each frequency.

The audio oscillator is a signal generator capable of producing signal voltages at frequencies in the audio range. The dial associated with the frequency control is calibrated in cycles per second.

One method for checking the gain of an amplifier at a specific frequency is to introduce a measured signal voltage at that frequency into the amplifier and measure the output-signal voltage. The gain of the stage is

$$\frac{e_o}{e_{in}} = \text{gain} \qquad (1)$$

The frequency response of an amplifier is a plot of gain or output vs. frequency at many frequency points. When these points are connected by a smooth curve, we have the response curve of the amplifier.

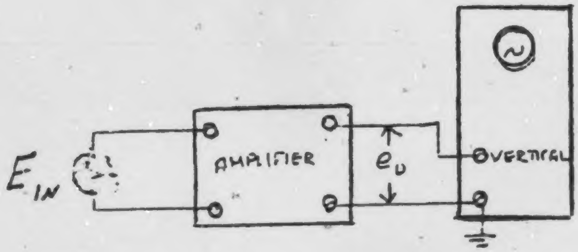


Fig. 1. Measuring output of amplifier.

Figure 1 represents an amplifier (which may consist of one or more stages), the signal source e_{in}, and the output signal voltage e_o, which is coupled to the vertical input terminals of an oscilloscope. If the output of the audio oscillator were constant over its entire frequency range, it would be possible to set e_{in} at some value, say 1 volt peak-to-peak, and simply monitor the output of e_o with an oscilloscope. However, the output of the audio oscillator does vary with frequency. Hence it is necessary to measure the output of the generator (e_{in}) for every frequency setting. This is the value of e_{in} that is used in substituting in the gain formula e_o/e_{in}.

Another method that can be used is maintain the output of the audio oscillator at a fixed value of e_{in}, say 1 volt peak-to-peak. This again requires the use of the scope for monitoring e_{in} for every frequency setting of the generator and adjusting the output control to maintain e_{in} at the desired level.

If a 1-volt peak-to-peak signal is used for e_{in}, the value of e_o is also the gain of the amplifier because

$$\text{Gain} = \frac{e_o}{e_{in}} = \frac{e_o}{1} = e_o \qquad (2)$$

Procedure;

1. Connect the amplifier of Fig. 2. The tride section of the 6SQ7 is used as the voltage amplifier. The 6K6 is the power amplifier. A 5-ohm 4-watt dummy load resistor is connected across the secondary of the output transformer.
2. Connect the output lead of the audio oscillator to the input of V_1, point A, and the ground lead to the ground of the circuit under test, point G.

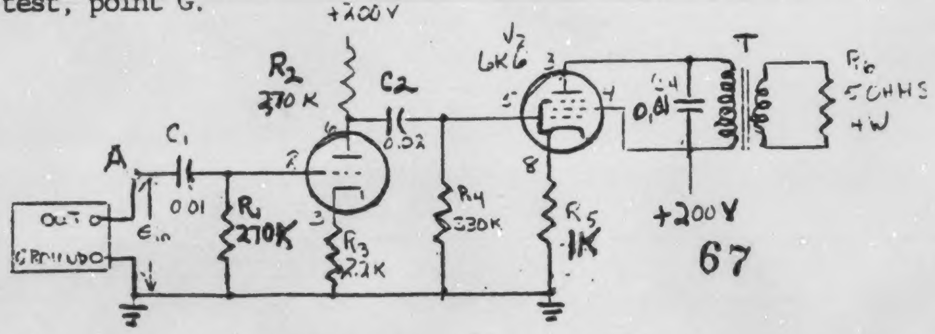


Fig. 2. Circuit for determining frequency response of amplifier.

3. Bring the frequency of the audio oscillator to 20 cps and set the output (e_{in}) to 1 volt peak to peak (use a scope for measuring e_{in}).

4. Measure with respect to ground and record in Table 1 the peak-to-peak signal voltage e_o at the plate of V_1.

5. Repeat Steps 3 and 4 for every frequency setting shown in Table 1.

6. Plot a graph from the data in Table 1 showing the output signal e_o vs. frequency response of the amplifier on logarithmic paper. Label curve "with C_4".

7. Remove C_4, the 0.01-uf capacitor across primary of T.

8. Repeat Steps 3, 4, 5, and 6. Plot the response curve on same graph paper as in Step 6 and label "without C_4".

Note: This circuit will be used in next job.

TABLE 1

Frequency, cps	e_o with C_4	e_o without C_4
20		
40		
60		
80		
100		
200		
400		
600		
800		
1,000		
2,000		
4,000		
6,000		
8,000		
10,000		
12,000		
15,000		

Questions:

1. What is meant by the "frequency response" of an amplifier?
2. How does capacitor C_1 affect the frequency responses of the amplifier? Explain.
3. How does capacitor C_4 affect the frequency response of the amplifier?
4. List the other circuit components in Fig. 2 which affect the frequency response.
5. Why is it necessary to monitor the output of the audio oscillator?
6. What are the limitations, if any, of using an A-C voltmeter for monitoring the output of the audio oscillator over the whole range of audio frequencies?
7. Can the gain of this amplifier be increased? How?

CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

Job Sheet 12
Page 1 of 7

Characteristics of Amplifiers

Objectives:

1. To learn how to determine the values of voltage and resistance which may be expected at the various tube-socket terminals of an audio amplifier.
2. To make resistance and voltage checks in an amplifier and compare the measured with the computed values.

Materials Required:

Power supply:	Variable + direct current, 6.3 volts rms
Equipment:	Oscilloscope, VTVM, audio oscillator.
Resistors:	1/2 watt, 2,200-ohm; two 270,000-ohm; 330,000-ohm; 1 watt, 1,000-ohm; 4 watts, 5-ohm.
Capacitors:	Two 0.01-uf, 0.02-uf
Tubes:	6SQ7, 6K6
Miscellaneous:	Audio output transformer

Introductory Information:

In servicing an audio amplifier, voltage and resistance checks are made at the tube-socket terminals. If the rated values of voltage and resistance are supplied, the technician has a reference source for comparing the measured value with the rated values. Frequently, however, rated values are not readily available. The technician must then know what values to expect so that he can recognize an abnormal reading.

You now have enough circuit knowledge and understanding to determine the resistance and voltage values you may expect at every test point in the amplifier.

1. Resistance Analysis

Resistance computations are based on simple knowledge of series, parallel, and series-parallel combinations of resistances. In the circuit of Fig. 1 assume that power is off and that all resistance measurements are made with respect to ground. At pin 5 of V_1, R_1 is a 100,000-ohm resistor connected to ground. There is no other resistor in parallel with R_1. Hence the resistance that an ohmeter would measure from pin 5 of V_1 to ground is 100,000 ohms x the tolerance of the resistor. The accuracy of the meter will also determine the actual value read. However, for all practical considerations it may be assumed that the resistance from pine 5 of V_1 to ground is approximately 100,000 ohms.

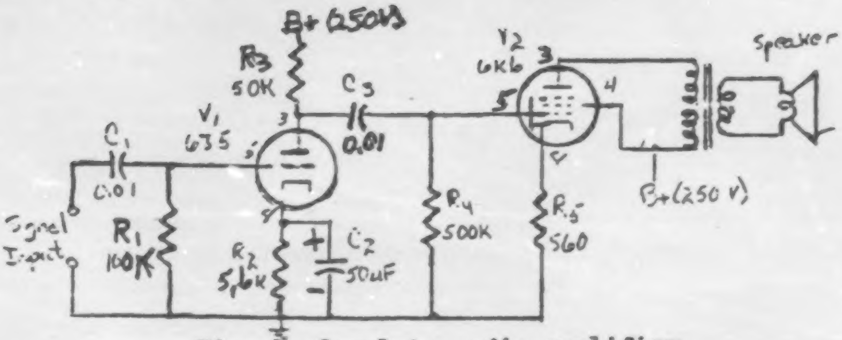

B+ (250V)
R3
50K
C3
0.01
V1
6J5
3
5
8
C1
0.01
Signal Input
R1
100K
R2
5.6K
+
-
C2
50uF
R4
500K
V2
6K6
3
4
5
8
R5
560
Speaker
B+(250 V)

Fig. 1. Complete audio amplifier.

The resistance from pin 8 of V_1 to ground is 5,600 ohms. The leakage resistance of C_2 is so high compared with the value of R_2 that it will not affect the reading.

The resistance from pin 3 of V_1 to ground presents a slightly different problem. It depends on the B+ supply circuit. Figure 2 is another view of the plate circuit (pin 3) of V_1 and the B+ supply, which is filtered by electrolytic capacitor C. When the ohmmeter leads are placed across pin 3 and ground, C starts to charge up to the battery voltage in the ohmmeter. As a result, the resistance read depends on how long the meter leads are kept in the circuit. The meter will register an increasing resistance with time. The final resistance reading will be 50,000 ohms plus the electrolytic leakage resistance.

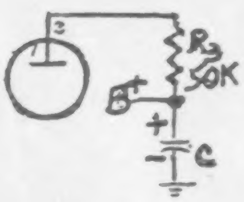


Fig. 2. Plate circuit.

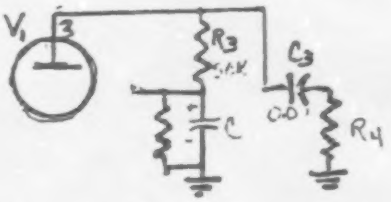

V1
3
R3
50K
C3
0.01
C
R4

Fig. 3. Plate circuit with B+ bleeder.

If, however, the B+ supply contains a bleeder resistor R across C, as in Fig. 3, and if R = 10,000 ohms, then the resistance read from pin 3 to ground would be 60,000 ohms. It should be noted the R_4 will not affect resistance readings at pin 3 of V_1, because C_3 acts as an open as far as direct current is concerned.

The previous considerations apply also to V_2. Hence resistance at pins 5 and 8 of V_2 would be, respectively, 500,000 and 560 ohms. At the plate and screen-grid circuits (pins 3 and 4, respectively) the resistance would depend on the B+ supply circuit. The resistance of the transformer primary is low compared with the B+-to-ground resistance, so that the readings at pins 3 and 4 will be approximately the same.

Resistance checks in the filament circuits will depend on how the filaments are connected. If the filaments are supplied by a 6.3-volt winding on the power transformer and if one lead of this winding is grounded, as in Fig. 4, then the resistance from pins 2 of V_2, or 8 of V_1, to ground is the resistance of the filament winding, which is very low, about 0.1 ohm. Filaments connected differently must be individually analyzed.

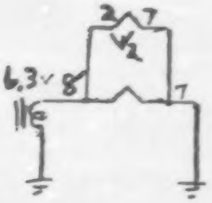


Fig. 4. Filament circuit.

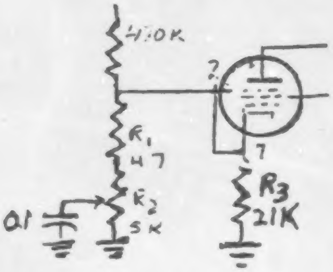


Fig. 5. Parallel branches.

Parallel connections must be considered in computing resistance. For example, in Fig. 5 the resistance at pin 2 or at pin 7 is determined by the parallel combination of the two branches shown. The R_T of this combination is approximately 5,000 ohms.

2. Direct-Current Voltage Analysis

Computing the D-C voltage at the tube-socket terminals can be fairly complex if accuracy is demanded. Where a high degree of accuracy is not required, approximations can be readily made.

In audio amplifiers it may be assumed that the amplifier is operating class A. Where push-pull amplifiers are used, the class of operation should be known.

In the circuit of Fig. 1, V_1 is a 6J5 tube whose plate supply is a 250-volt source. It is now necessary to refer to the normal operating conditions of this tube. A tube manual shows that if the 6J5 is operated class A with a plate supply of 250-volts, the bias is -8 volts approximately. Since V_1 in Fig. 1 is cathode-biased, there is therefore 8 volts at the cathode. Hence the voltage from pin 8 to ground in V_1 is 8 volts.

Since cathode current and plate current I_p are the same in this tube, we can find I_p, knowing that there is 8 volts across a 5,600-ohm cathode resistor. Thus:

$$I_p = \frac{8}{5,600} = 0.0014 \text{ amp.}$$

Now, to determine the plate voltage of V_1, simply find the voltage drop across the plate-load resistor and subtract this value from the B+ supply. This $I_p \times R_L$ = (0.0014) (50,000) - 70 volts. Therefore, $E_p = 250 - 70 = 180$ volts, approximately.

The voltage with respect to ground at pin 5 of V_1 is zero, since the grid, pin 5, is returned to ground and there is no direct current in the grid circuit.

Similarly, in V_2, grid voltage is zero (pin 5) and a tube manual shows that the cathode (pin 8) voltage is 18 volts approximately. The plate current I_p is about 33 ma. The resistance of the primary of the output transformer is several hundred ohms. There is therefore a small voltage drop (about 10 volts) across this primary resistance. The plate voltage (pin 3) is about 240 volts, and the screen voltage (pin 4) is 250 volts.

From actual experience the technician learns what percentage of the power-supply voltage he will find on the plate of a voltage amplifier, under normal operating conditions. He also knows that the plate and screen voltages of a power amplifier are almost the same and are close to the B+ supply source, unless a voltage dropping resistor is used in the plate or screen. As far as the cathode voltage is concerned, where cathode bias is used, he knows that it is low in voltage amplifiers and high in power amplifiers.

Filament circuits are checked for filament voltage. The technician must know how the filaments are connected and fed. In most cases alternating current is used for heating the filaments. In some applications, such as portable radios, direct current is used as the filament source. Filament voltage is checked across the filaments. The tube-type designation indicates the amount of filament voltage which may be exp-cted.

Certain facts now become apparent. These are

1. In an amplifier which is cathode-biased (has a resistor in the cathode circuit), current through the tube will result in a voltage drop across the cathode. No voltage at the cathode would mean that there is no current in the tube or a short across the cathode resistor.

2. Similarly, current in a plate and screen-grid circuit results in a voltage drop across the plate and screen-grid resistor. The voltage at the plate and screen is lower than the supply source by an amount equal to the drop across each resistor. If the plate or screen voltage is the same as the supply voltage, it is because there is no I_R drop across the resistors in these circuits. This may be caused either by no current flow or by a short across the resistors in the plate or screen-grid circuits.

3. If the plate or screen-grid resistor is open, there will be no voltage at the plate or screen, respectively.

Procedure:

Note 1: The amplifier connected in Job 11 (Fig. 2) is again used here.
Note 2: All readings are made with respect to ground.

1. a. Estimate and record the values of resistance and voltage at every test point shown in Table 1. Assume that the tube is operating normally. If a voltage is A-C at a specific test point, indicate it in the charge. Otherwise, it is presumed to be D-C.

   b. Fill in the tube element corresponding to each number in the appropriate column.

2. Power Off. Measure and record resistance at every test point shown in Table 1.

3. Power On: Measure and record the voltage at every test point shown in Table 1.

4. Remove V_1 and V_2.

5. Measure and record the voltage at every test point shown in Table 1.

Questions:

1. What is the significance of zero voltage at the
   a. Cathode of a self-biased amplifier?
   b. Plate of a voltage amplifier using a plate-load resistor R_L?
   c. Control grid of a class A amplifier using cathode bias?

2. What is the significance of measuring full supply voltage at the plate and screen-grid of a voltage amplifier if the plate load $R_L = 50,000$ ohms and the screen dropping resistor $R_{sc} = 10,000$ ohms?

3. In a class A voltage amplifier will the signal voltage alter the D-C voltages at: (a) Cathode? (b) Plate?

4. In the circuit of Fig. 1, what would be the meaning of measuring an infinite resistance between pins 3 and 4 of V_2?

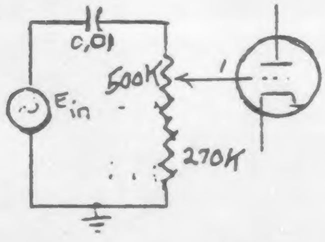
5. a. In the circuit of Fig. 1, what would be the meaning of measuring 10,000 ohms in the cathode of V_1?
   b. Approximately how much voltage can be expected at the cathode, if the resistance from pin 8 to ground measure 10,000 ohms?

6. What is the range of resistance which may be expected at pin 1 of Fig. 6?

TABLE 1

Tube	Element	Pin No.	Resistance		Voltage		
			Estimated	Measured	Estimated, tube in	Measured	
						Tube in	Tube out
V_1 6SQ7		1					
		2					
		3					
		4					
		5					
		6					
		7					
		8					
V2 6K6		1					
		2					
		3					
		4					
		5					
		6					
		7					
		8					

Fig. 6. Grid-circuit resistance.



CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

Information Sheet 1
Page 1 of 4

TRANSFORMERS

General Information:

A transformer is a device that has no moving parts and that transfers energy from one circuit to another by electromagnetic induction. The energy is always transferred without a change in frequency, but usually with changes in voltage and current.

A step-up transformer receives electrical energy at one voltage and delivers it at a higher voltage. Conversely, a step down transformer receives energy at one voltage and delivers at a lower voltage.

Transformers require very little care and maintenance because of their simple, rugged and durable construction. The efficiency of transformers is high. Because of this, transformers are responsible for the more extensive use of alternating current than direct current. The conventional constant-potential transformer is designed to operate with the primary connected across a constant-potential source to provide a secondary voltage that is substantially constant from no load to full load.

Various types of small single-phase transformers are used in factory, commercial and residential equipment. In many installations, transformers are used on switchboards to stepdown the voltage for indicating lights. Low voltage transformers are included in some motor control panels to supply control circuits or to operate overload relays. Other common uses include low voltage control for residential wiring, ignition transformers for automatic oil burners. Electronic circuits and devices employ many types of transformers to provide necessary voltage for proper electron-tube operation, interstage coupling, signal amplification, and so forth. The physical construction of these transformers differs widely.

The Power Supply Transformer used in electronic circuits is a single-phase constant-potential type with one or more secondary windings, or a single secondary with several tap connections. These transformers have a low voltage ampere capacity and are less efficient than large constant-potential power transformers. Most power-supply transformers for electronic equipment are designed to operate on 50 to 60 cycles per second. Air-craft power-supply transformers are designed for a frequency of 400 cycles per second.

The higher frequencies permit a saving in size and weight of transformers, and associated equipment.

Instrument Transformers include Potential or Voltage Transformers and Current Transformers. These transformers are usually step-down type and are usually used with A-C instruments when high voltages or large currents are to be measured.

Construction

The typical transformer has two windings insulated from each other. These windings are wound on a common magnetic circuit made of laminated sheet metal. The principal parts are: (1) The Core, which provides a circuit of low reluctance for the magnetic flux; (2) The Primary Winding, which receives the energy from the A-C source; (3) The Secondary Winding, which receives the energy by mutual induction from the primary and delivers it to the load, (4) The Enclosure.

When a transformer is used to step-up the voltage, the low voltage winding is the primary. Conversely, when a transformer is used to step down the voltage, the high-voltage winding is the primary. The primary is always connected to the source of power; the secondary is always connected to the load. It is common practice to refer to the winding as the primary and secondary rather than the high or low voltage windings.

The principal types of transformer construction are the core type and the shell type. The cores are built of thin stampings of silicon steel. EDDY currents, generated in the core by the alternating flux as it cuts through the iron, are minimized by using thin laminations and by insulating adjacent laminations with insulating varnish. Hysteresis losses, caused by friction developed between particles as they are rotated through each cycle of magnetization, are minimized by using a special grade of heat-treated grain-oriented silicon-steel laminations.

In the core-type transformer, the copper windings surround the laminated iron core. In the shell-type transformer the Iron core surrounds the copper windings. Distribution Transformers are generally of the core type; where as some of the largest power transformers are of the shell type.

If the winding of a core-type transformer was placed on separate legs of the core, a relatively large amount of the flux produced by the primary winding would fail to link the secondary winding and a large leakage flux would result. The effect of the leakage flux would be to increase the leakage reactance drop, IX_L in both windings. To reduce the leakage flux and reactance drop, the windings are subdivided and half of each winding is placed on each leg of the core. The winding may be cylindrical in form and placed one inside the other with the necessary insulation. The low voltage winding is placed with a large part of its surface area next to the core, and the high voltage winding is placed outside the low voltage winding in order to reduce the insulation requirements of the two windings. If the high-voltage winding were placed next to the core, two layers of high-voltage insulation would be required, one next to the core and the other between the two windings.

In another method, the windings are built up in thin flat sections called pancake coils. These pancake coils are sandwiched together, with the required insulation between them. In commercial transformers the complete assembly is usually immersed in a special mineral oil to provide a means of insulation and cooling.

Transformers are built in both single-phase and polyphase units. A 3-phase transformer consists of separate insulated windings for the different phases, wound on a 3-legged core capable of establishing three magnetic fluxes displaced 120° in time phase. Three phase transformers are not as popular as three single phase transformers connected into a three phase connection. Damage to a three phase unit would result in complete loss of the three phase system in comparison to three separate single phase delta connected transformers. If one transformer is damaged in such a system, it can be removed and the remaining two transformers can be reconnected open delta to supply the three phase service, but at a reduction in the original load capacity of the transformer bank.

Voltage and Current Relations

The operation of the transformer is based on the principle that electrical energy can be transferred efficiently by mutual induction from one winding to another. When the primary winding is energized from an A-C source, an alternating magnetic flux is established in the transformer core. This flux links the turns of both primary and secondary, thereby inducing voltages in them. Because the same flux cuts both windings, the same voltage is induced in each turn of both windings. Hence, the total induced voltage in each winding is proportional to the number of turns that are in that winding. That is,

$$\frac{E_p}{E_s} = \frac{N_p}{N_s}$$

where E_p and E_s are the induced voltages in the primary and secondary windings, respectively. In ordinary transformers the induced primary voltage is almost equal to the applied primary voltage; hence, the applied primary voltage and the secondary induced voltage are approximately proportional to the respective number of turns in the two windings.

A constant-potential single phase transformer is represented by the schematic diagram in Fig. 1, A. For simplicity, the primary winding is shown as being on one leg of the core and the secondary winding on the other leg. The equation for the voltage induced in one winding of the transformer is

$$E = \frac{4.44\ BSFN}{10^8}$$

where E is the R.M.S. voltage, B the maximum value of flux density in lines per square inch in the core, S the cross-sectional area of the core in square inches, F the frequency in cycles per second, and N the number of complete turns in the winding.

For example, if the maximum flux density is 90,000 lines per square inch, the cross-sectional area of the core is 4.18 square inches, the frequency is 60 cycles per second and the number of turns in the high voltage winding is 1,100, the voltage rating of this winding is

$$E_1 \ \underline{4.44 \times 90{,}000 \times 4.18 \times 60 \times 1{,}100} = 1{,}100 \text{ volts}$$

If the primary - to - secondary turns ratio of this transformer is 10 to 1, the number of turns in the low-voltage winding will be:

$$T_s = \frac{1{,}100}{10} = 110 \text{ turns}$$

The voltage induced into the secondary will be:

$$E_s = \frac{1{,}100}{10} = 110 \text{ volts}$$

When a load is connected to the secondary by closing switch in Fig. 1, the secondary current depends on the secondary voltage and the impedance of the load, Z. For example, if secondary voltage is 110 volts and the impedance is 22 ohms, the secondary current will be:

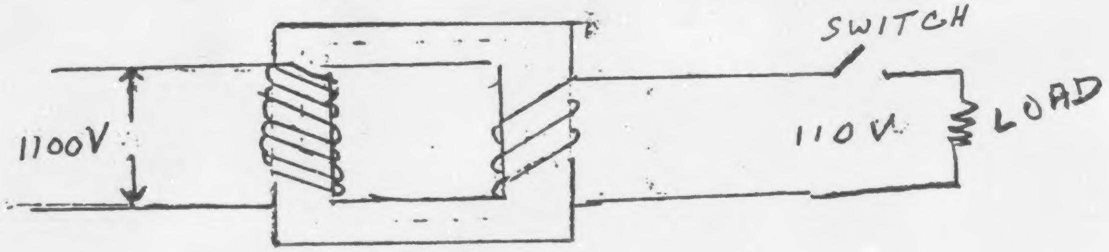
$$I_2 = \frac{E_2}{Z_2} = \frac{110}{22} = 5 \text{ amperes}$$

The secondary load current flowing through the secondary turns comprises a load component of magnetomotive force, which, according to Lenz, is in such a direction as to oppose the flux which is producing it. This opposition tends to reduce the transformer flux a slight amount. The reduction in flux is accompanied by a reduction in counter voltage induced in the primary winding of the transformer. Because the internal impedance of the primary winding is low and the primary current is limited principally by the counter EMF in the winding, the transformer primary current increases when the counter EMF in the primary is reduced.

The secondary current controls the current in the primary because it is an induced current. It is always slightly less than the primary due to copper and core losses. On a step-down transformer, current will be greater than the primary if the wire is large enough. For example; a transformer with 1,100 volt primary with a current of 5 amps flowing, if the secondary voltage is 110 volts, 50 amps could flow in the secondary. This 50 amps is in a transformer that is 100% efficient.

$$\frac{E_p}{E_s} = \frac{I_s}{E_p} = \frac{1,100}{110} = \frac{50}{5} = 5,500 \text{ Volt-amps or } 5.5 \text{ KVA}$$

Transformers are rated in volt-amps or larger transformers in KVA (kilo-volt-amps). No transformer is 100% efficient due to Eddy currents, hysteresis, and copper losses. The transformers, when fully utilized, are 94 - 98% efficient.



10 TO 1 TURNS RATIO

CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

Job Sheet 13
Page 1 of 3

Power Supplies

Objectives:

1. To study the physical and electrical characteristics of power transformers used in radio.
2. To learn the RETMA color code for the windings.
3. To check the resistance values of the windings.

Materials Required:

Equipment: VTVM
Miscellaneous: Radio power transformer

Introductory Information:

Power transformers used in A-C radios perform several functions. First, they are used to step up the A-C line voltage, which is then rectified and changed into D-C voltage. Second, the transformer is used to step down the line voltage to a vlue required to supply the filaments of the tubes in the receiver. Third, the transformer serves to isolate windings from each other.

The windings of a radio power transformer are around a laminated iron core. The purpose of the laminations is to reduce the eddy-current losses in the core.

Figure 1 is the schematic diagram of a conventional power transformer. This transformer has a primary winding which is connected to the A-C line-voltage source.

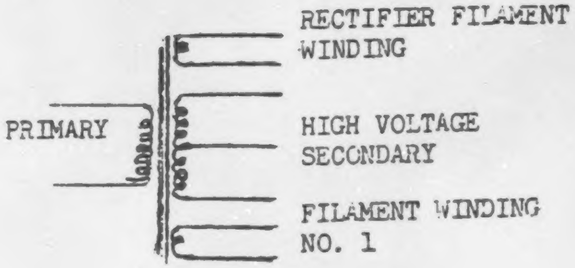


Fig. 1. Diagram power transformer

The high-voltage secondary is usually a center-tapped voltage stepup winding. The tap is the A-C center of this winding. The voltage induced in the secondary depends on the turns ratio. If the high-voltage secondary is rated 260-0-260, it means that at the top and bottom of the winding there is 260 volts rms with respect to the center tap. Across this entire winding there is 520 volts rms. The outside leads are connected to the two plates of a full-wave rectifier, and the center tap is used as the return.

There are two filament windings shown for this transformer. The rectifier-filament winding usually supplies 5 volts of filament voltage to the vacuum-tube rectifier. The other winding (filament winding 1) is used as a supply for the filaments of the other tubes in a receiver, and is usually rated at 6.3 volts.

The secondary windings of a power transformer are also rated for their current capacity. Current flowing through the windings generates heat. If there is excessive current in a winding (beyond the rated value), it may burn out.

The high-voltage winding is rated for the maximum direct current which can safely flow through it. Thus the more direct current that is required by a receiver, the higher must be the current rating for this winding. The direct currents draw range from about 50 ma for the smallest to 150 ma for the largest radio receiver.

The A-C rating for the rectifier filament winding may vary from 2 to 3 amp. Filament winding 1 may be rated for 2 to 5 amp alternating current.

A power transformer may have other secondary windings. Moreover, filament windings may also be center-tapped, and high-voltage windings may contain special taps for specific applications.

The resistance of each of the windings depends on the number of turns and upon the diameter of the wire. Generally, the filament windings have the least resistance, less than 1 ohm. The high-voltage secondary has the most resistance, several hundred ohms or somewhat more. The primary resistance is in the range of 5 ohms.

Power transformer winding leads are color-coded so that the technician may readily identify them. Figure 2 shows the RETMA code which is in general use in the radio and television industry.

There are variations from this code. It is good practice to refer to the legend either on the transformer or in the accompanying packing box for the color code of a specific transformer.

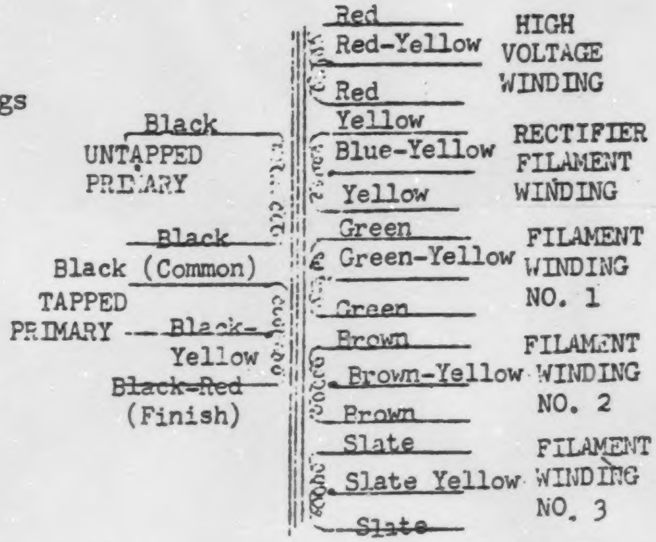

Red
Red-Yellow
Red
HIGH VOLTAGE WINDING
Yellow
Blue-Yellow
Yellow
RECTIFIER FILAMENT WINDING
Green
Green-Yellow
Green
FILAMENT WINDING NO. 1
Brown
Brown-Yellow
Brown
FILAMENT WINDING NO. 2
Slate
Slate Yellow
Slate
FILAMENT WINDING NO. 3
Black
UNTAPPED PRIMARY
Black
Black (Common)
TAPPED PRIMARY
Black-Yellow
Black-Red (Finish)

Fig. 2. RETMA color code for power transformer.

Procedure:

1. Examine the power transformer. Check and record in Table 1 the color code for the winding leads.
2. Measure the resistance of each of the windings and record in Table 1. For all tapped windings, measure total resistance of each end to the tap.

TABLE 1

Winding	Color Leads		Resistance	
Primary if tapped	Common		1. Total	
	Tap		2. Common to tap	
	Finish		3. Finish to tap	
High-voltage secondary	Plates		1. Total.	
	Tap		2. Plate 1 to tap	
			3. Plate 2 to tap	
Rectifier filament	Filaments		1. Total	
	Tap		2. Connection 1 to tap	
			3. Connection 2 to tap	
Filament 1	Filaments		1. Total	
	Tap		2. Connection 1 to tap	
			3. Connection 2 to tap	
Additional winding				

Questions:

1. What are the voltage and current ratings if given, of the
   - a. High-voltage winding?
   - b. Rectifier filament winding?
   - c. Filament 1 winding?
   - d. Primary winding?
2. A power transformer with a 5-ohm D-C primary resistance is used in a radio which consumes about 100 watts. Assume a 117-volt rms input, 100 percent transformer efficiency, and unity power factory.
   - a, How much alternating current will flow in the primary of this transformer under normal operation?
   - b. How much current will flow when 117 volts D-C is placed across the primary of this transformer?
   - c. What would ahppen to the primary winding under the conditions in Question 2b?
   - d. Why doesn't this happen when 117 volts A-C is placed across the transformer primary?
3. Why must a radio using a power transformer never be plugged into direct current?

CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

Job Sheet 14
Page 1 of 2

Voltage Regulators

Objectives:

1. Understanding the operation of a Voltage Regulator tube.
2. Application of Voltage Regulator tubes.

Material Required:

Voltage Regulator tube OC3/VR 105 and socket;
DC Power Supply 0-150-V
Resistors - Limiting and load (size to be computed)
Single Pole switch
2 DC Voltmeters 0-150 V
DC Ammeter 0-50 ma.

Introductory Information:

The voltage regulator tube consists of a cathode and plate enclosed in a glass shell containing a gas at a low pressure. There being no filament, the tube is known as a cold cathode type tube. When the potential difference is large enough between the plate and cathode the tube will conduct. This conduction results in a bluish glow of gas within the tube. The greater the current, the brighter the glow will be. The voltage drop across the tube will remain nearly constant provided the current is within the tube limits.

Previously voltage regulator tubes were identified as VR-150/30, VR-90/30, VR-75/30, etc. The VR represented voltage regulator; the first set of numbers the voltage at which it regulated; the numbers under the slant line the maximum current rating. Now they are designated as OA_2, OA_3, OC_3, etc., and the manufacturer's specifications or a tube manual must be consulted to determine the tube ratings.

The OC3 which you will use has a D.C. operating voltage of 108 and a current range from 5 ma to 30 ma. Pin 2 is the cathode, pin 5 the plate and pins 3 and 7 are internally connected. Note in Fig. 1 that if the OC3 is removed from its socket the circuit between the power supply and the load is opened.

To determine the size dropping resistor required, assume a no load condition, maximum current for which the V.R. tube is rated, and using Ohm's Law find R. The E will be the arithmatical difference between the power supply voltage and the regulated voltage. If the computed R is not a standard size resistor use the next larger standard size. This is to insure that the current limits of the tube are not exceeded. The resistor wattage may be found by the use of the formula $P = EI$.

Studying Fig. 1 you will notice that the V.R. tube is in parallel with the load and the dropping resistor is in series with this parallel combination; therefore, the current in the dropping resistor is the sum of the load and V.R. currents. This prohibits the load current from exceeding the difference between the minimum and maximum current ratings of the V.R. tube, which is 25 ma for the OC3. Should the load current exceed this value, the V.R. tube will cease to conduct and only the load will be in series with the dropping resistor. The voltage under these conditions will be determined on the series circuit laws.

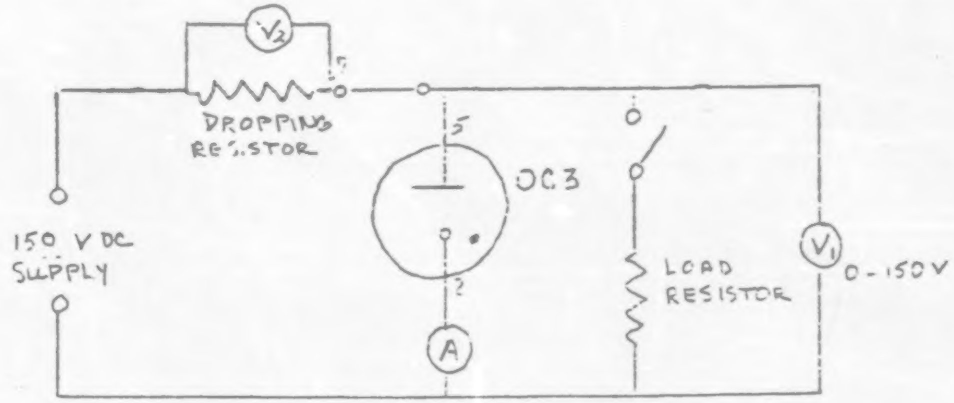


Fig. 1.

Procedure:

1. Compute value of load resistor for 25 ma at 108v.
2. Compute value of dropping resistor required for the OC3 when the power supply is set for 150 V.D.C.
3. Connect components as shown in Fig. 1.
4. Re-check computed values of the resistors.
5. With single pole switch open energize circuit and record values indicated by the meters.
6. Close the switch and record values indicated by the meters.
7. Replace load resistor with resistors that at 108 volts will cause the load current to be the following: (a) 15 ma, (b) 10 ma, (c) 5 ma, (d) 40 ma. Repeat step 7 for each load resistor.
8. Replace load resistor for 25 ma load current and reduce the voltage in 10 volt increments to 100 volts. Open the switch while making the change. Record meter values.

Questions:

1. Does the resistance of the tube vary when the amount of current varies? Explain your answer.
2. What conditions will cause the tube to operate properly even though the tube is good?
3. What was the voltage regulation of this tube for each of the five different loads?
4. What effect was there when you reduced the voltage?
5. List several conditions where it would be necessary to use a voltage regulator.

CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

Job Sheet 15
Page 1 of 2

Three-Phase

Objectives:

1. To learn how three-phase A.C. may be rectified.
2. Understanding the advantages of using three-phase.

Materials Required:

Three-phase anode transformer, secondary 500 ma at 350 to 450 volts.
Mercury vapor tubes, 3 No. 83 tubes.
Filament transformer, 9 amperes at 5 volts, center tap.
Load resistor - 2 K-ohm, 100 watts
D.C. Milliammeter - 0-500
D.C. Voltmeter, 500 volt scale.
Oscilloscope

Introductory Information:

Power supplies discussed this far have been types utilizing single-phase A-C input sources. The following rectifier (Fig. 1) uses a poly or 3-phase source with the primary of the power transformer delta-connected and the secondary being wye. The secondary windings are separated by 120 electrical degrees. The load resistor R_L is connected between the center tap of the wye and the center tap of the filament transformer. Fig. 2 shows the wave forms of the three-phase A-C input with the have-wave output of each tube. The output across R_L (Fig. 2) has a pulsating frequency three times that of the supply frequency. This higher frequency allows the use of smaller capacitors than may be used in single-phase supplies to obtain adequate filtering. Also a higher power efficiency is obtained using three-phase which makes it more adaptable to use in high-power requirement equipment such as welders, plating dielectric and induction heating.

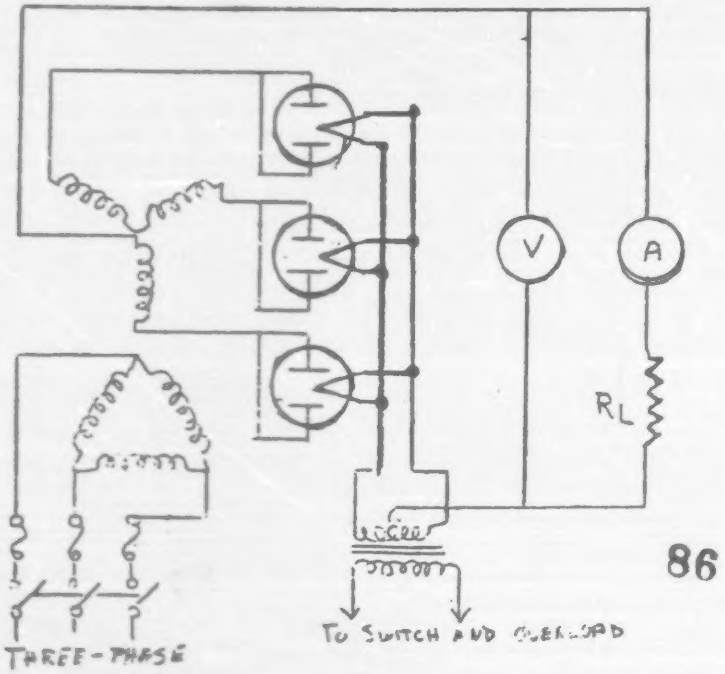


Fig. 1

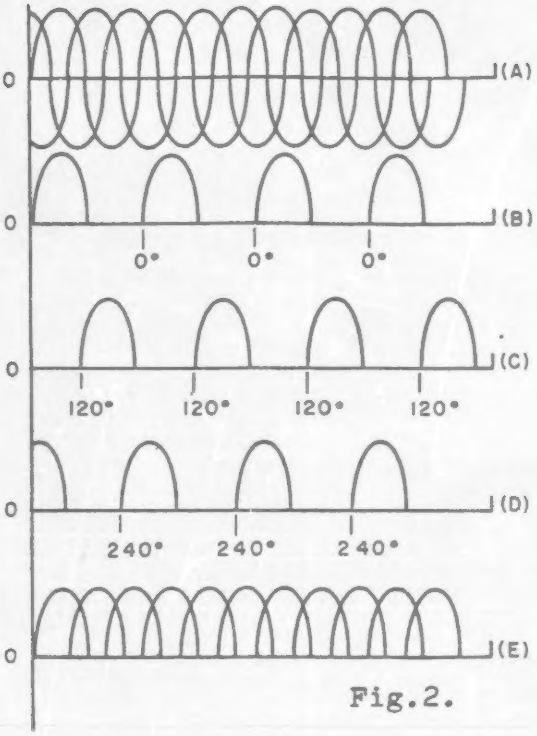


Fig.2.

Procedure:

1. Connect the circuit components as in Fig. 1. If filament supply is taken from ungrounded three-phase, be sure to use double pole switch.
2. Check that your wiring and connections are correct. Connect oscilloscope across load resistor.
3. Close the filament supply switch and allow tube to reach operating temperature (at least 60 seconds).
4. When tubes are at operating temperature close switch in primary of anode tube. Read and record values indicated by voltmeter and ammeter. Note ripple pattern and compare to single phase rectification.
5. Open anode switch and the filament switch.
6. Remove load resistor, oscilloscope and milliammeter from circuit.
7. Energize circuit again (close filament circuit first) and record value of output voltage with no load.
8. Calculate voltage regulation of power supply. If possible, repeat the entire job with a choke input filter connected. Compare the regulation with and without the filter.

Questions:

1. Why is it necessary to have the tubes at operating temperature before energizing the plate supply?
2. Explain the purpose of the center tap on the filament transformer.
3. Explain why the power efficiency is greater when using a polyphase rectifier?
4. Is this circuit considered a have-wave of full?
5. What are the advantages of polyphase rectifiers?

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BASIC ELECTRONICS

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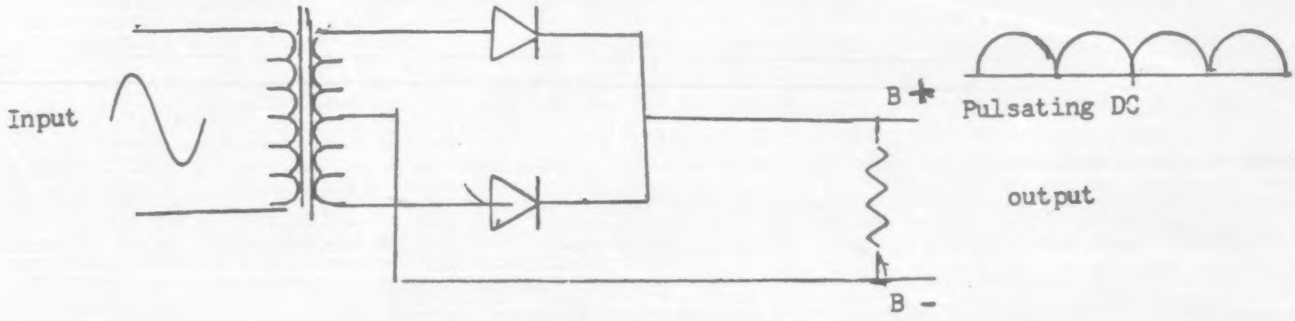
SOLID STATE

Electronic tubes used as power supplied and amplifiers have some disadvantages. They are fragile due to the heat they generate and are quite expensive. Engineers discovered certain combinations of materials cause current to flow easier in one direction than in the other. This device has low forward resistance and a high reverse resistance. A base metal with a layer of selenium and a counter-electrode of metal makes a solid state diode and can be used in place of an electron tube.

Placing two of them across the outside legs of the secondary of a center tapped transformer will make a full wave rectifier circuit.



Transistors:

Transistors were invented just a few years ago. Since that time millions have been used in a great variety of electronic devices. The term transistor comes from the combination of two words - "transfer resistor". The resistor transfers small values of electrical energy into larger values. Weak voltages can be made strong enough by transistor circuits to operate a speaker or relay.

A transistor is actually a variable resistor, but not of the ordinary type. It is unique because its resistance can be varied electrically. Small incoming voltages cause small currents to flow through the transistor. The small currents make corresponding but large changes in the transistor resistance, causing other transistor currents to make large value changes. The output signal is similar but stronger than the input signals.

Transistors are classified as semiconductors and are made of silicon and germanium. Since a transistor will make small input voltages into large output currents, they will amplify. The transistor is replacing the tube for several reasons. They are smaller in size, need no heater current and are relatively noise free.

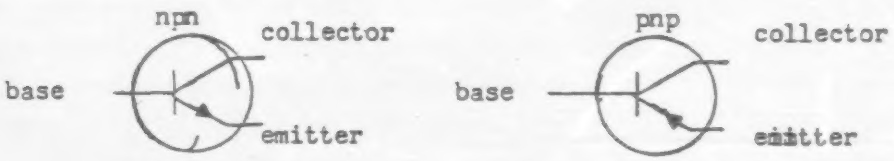
Like diodes and rectifiers, the transistors are composed of p and n materials, or germanium and silicon "doped" with impurities. (The terms, doped and doping, are used with reference to the impurities added to the semi-conducting materials).

Transistors are composed of n material placed between two p materials or p material between two n materials. Depending on the construction, transistors are referred to as npn or pnp type transistors.

The circuit application dictates the transistor characteristics and construction needed. Such factors as voltage available and applied, current the device will and must pass, and the temperture the device must endure.

The transistor, composed of npn or pnp material, has three main parts. These are called emitter, collector, and base. With three connections the transistor can be connected in a circuit in several ways.

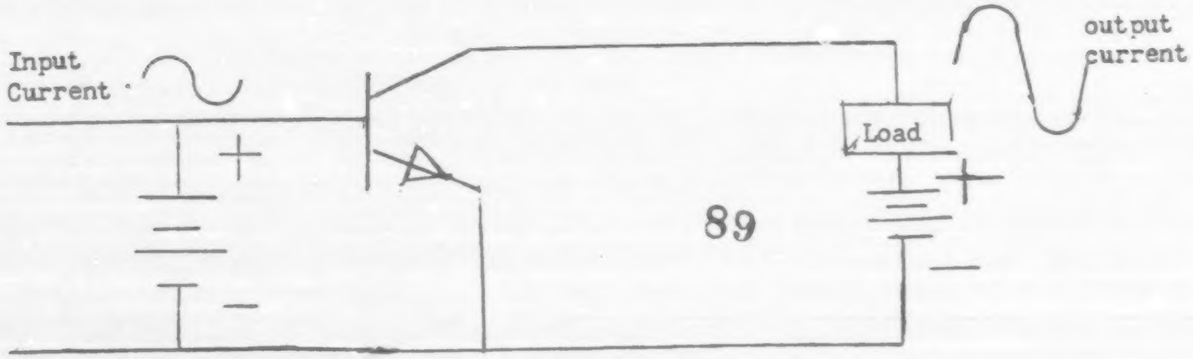
Transistor symbols:



Transistors are most often used as amplifiers. In the transistor radio they take the slight radio input signal and amplify it until it is strong enough to operate the speaker.

In solid state controls, transistors are used to amplify small signals obtained from sensors to provide enough power to do some useful work such as switching through a contactor or controlling motors or lighting. More recently, they are used to operate a solid state switch, the silicon controlled rectifier (SCR).

When the transistor is connected in a circuit for amplification, it is usually connected common emitter. The term common emitter defines how the transistor is connected with respect to the input and output signal.



CONNECTICUT STATE VOCATIONAL SCHOOLS

BASIC ELECTRONICS

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Half Wave Rectifier

Objectives:

1. To study the selenium rectifier and circuit connections for a half-wave supply and filter.
2. To determine the amplitude of ripple and D-C voltage output under load.

Materials Required:

Equipment:	Oscilloscope, VTVM
Resistors:	3 watts, 5-ohm; 5 watts, 5,000-ohm, 10,000-ohm, 500-ohm
Capacitors:	40-uf, 20-uf, 200 volts, electrolytic
Rectifier:	75-ma selenium

Introductory Information:

The usefulness of a vacuum-tube diode as a rectifier arises from the fact that it permits current to flow in only one direction. There are other devices in addition to the vacuum tube which possess this property.

One such device is the metallic selenium rectifier. This rectifier consists of stacked cells. Each cell is made of a metal plate coated with selenium, over which an alloy is sprayed. The electrical symbol for the selenium rectifier is shown in Fig. 37-1(a). The equivalent circuit Fig. 37-1(b) indicates that the selenium coated base (A) corresponds to the plate and the alloy (B) corresponds to the cathode of a vacuum-tube diode.

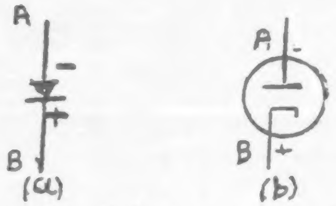

Fig. 37-1. (a) Selenium rectifier and (b) vacuum-tube equivalent.

The rectifier cell has a low forward resistance to electron flow and a high back resistance. That is, if A is made positive with respect to B, there will be electron flow from B to A (low forward resistance). If A is made negative with respect to B, there will be no electron flow through the cell (high back resistance). This property of the selenium rectifier makes it comparable to the electron-flow characteristics of a diode, and it may be used in place of the vacuum diode to rectify an A-C voltage. Seleniums, however, have no filaments as do vacuum-tube rectifiers and hence require no filament voltage.

Selenium rectifiers used in radio and television consist of combinations of cells. Each cell can handle 24 to 26 volts. The area of the cell determines how much current it can safely carry.

Manufacturer's ratings for a selenium rectifier usually include

1. Maximum direct current it can handle.
2. Maximum rms input voltage.
3. Maximum inverse peak voltage.
4. Maximum peak current.

For mounting in radio or television chassis, the rectifier usually has an insulated hole through the center. This will hold a 6-32 machine screw. Some late-model rectifiers are socket-mounted. Socket mounting simplifies replacement of selenium rectifiers which have become defective.

Figure 2 is the schematic diagram of a typical selenium half-wave rectifier power supply found in many portable radios. No transformer is used. Hence there is no isolation from the line, and the ground return (G) of the supply is directly connected to the line. In checking this type of supply, it is therefore advisable to plug into an isolation transformer.

C_1, R_1, and C_2 constitute the filter. C_1 and C_2 are electrolytic capacitors and are rated at 150 volts D-C. Because R_1 takes the place of a filter choke, large capacitors are required to insure proper filtering. Hence, C_1 and C_2 are usually 40- and 20-uf capacitors. R_2 is a surge-current-limiting resistor to protect the selenium.

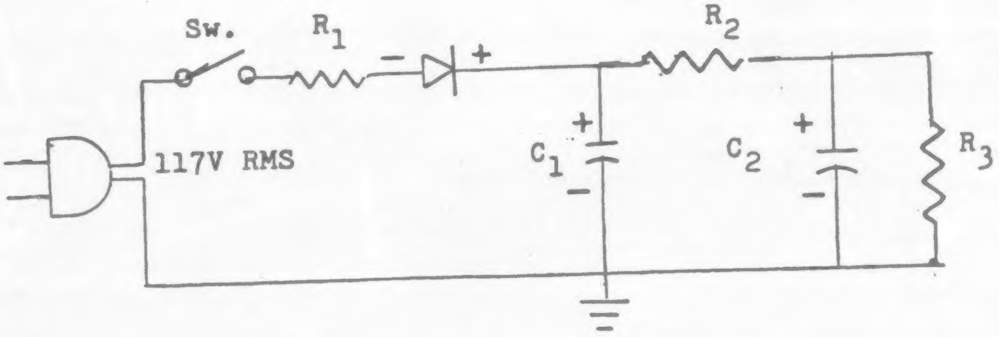

Fig. 2. Selenium rectifier half-wave power supply

Operation of this rectifier is similar to that of the half-wave supply of a conventional vacuum-tube rectifier. On the positive alternations of the input voltage there is electron flow through the rectifier. On the negative alternations there is no current. The resultant 60-cps pulsating direct current is filtered and appears as a ripple-free D-C voltage (B+) at point P. R_3 is a bleeder resistor.

Proper polarity must be observed in connecting the filter capacitors and the selenium rectifier in the circuit. The two connectors of the rectifier will be labeled - and +. The + side is connected to C_1.

Procedure:

1. Connect the circuit of Fig. 2. C_1 and C_2 are 40- and 20-uf at 200 volts, respectively. R_1 is a 500-ohm 5-watt resistor. R_2 is a 5-ohm 3-watt resistor. R_3 is a 10,000-ohm 5-watt resistor. The selenium is at 75 ma, 125 volts.

   Have your connections checked by an instructor.

   Caution: Connect the supply into an isolation transformer to avoid shock hazard and possible damage to components and equipment.

2. Power On. Measure and record in Table 1 the no-load D-C voltage at points P (B+) and A.

TABLE 1

	No load			With load		
		Ripple			Ripple	
Point	D-C volts	Waveform	Peak-to-Peak volts	D-C volts	Waveform	Peak=to-peak volts
P(B+)						
A						

3. With an oscilloscope observe, measure, and record in Table 1 the ripple voltage at points P and A.

4. Power Off. Connect a 5,000-ohm 5-watt load resistor in parallel with R_3.

5. Power On. Repeat measurements of Steps 2 and 3 with load and record in Table 1.

6. Power Off. Open capacitor C_1.

7. Power On. Repeat D-C and ripple measurements as in Steps 2 and 3 with load and record in Table 2.

8. Power Off. Replace C_1 in the circuit, as in Fig. 2. Open C_2.

9. Power ON. Repeat Step 7 measurements and record in Table 2.

10. Power Off. Replace C_2 in the circuit as in Fig. 2. Open R_1.

11. Power On. Repeat step 7 measurements and record in Table 2.

TABLE 2

Open Filter Component	Point	D-C volts	Ripple	
			Waveform	Peak-to-Peak volts
C_1	P			
	A			
C_2	P			
	A			
C_3	P			
	A			

Questions:

1. Compute the bleeder current drawn in the circuit of Fig. 2 without load. Show all computations.
2. Compute the load current drawn in the circuit of Fig. 2. Show all computations.
3. Compute the percentage of regulation of this supply.
4. Explain the operation of the half-wave selenium rectifier circuit.
5. Draw a diagram and explain the use of an isolation transformer.
6. What precautions must be observed in connecting the circuit of Fig. 2? Why?
7. Which is more effective in maintaining a high B+ output, C_1 or C_2? Why?
8. What advantages are there in using selenium rectifiers?

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BASIC ELECTRONICS

Job Sheet 17
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Transistor Characteristic Curves

* Study Basic Electronics, Johannsen and Journigan, Pages 178-179

Objectives:

A. To determine and plot the family of collector volt-collector current characteristic curves for a common-base configuration.

B. To determine and plot the family of collector volt-collector current characteristic curves for a common-emitter configuration.

APPARATUS

1.- Type 2N1175 transistor
1 - Resistor, 470 ohms, 1/2 watt
1 - Potentiometer, 5 K, 2 watts
1.- Potentiometer, 1 K, 2 watts
2 - Vacuum tube voltmeters

2 - S.P.S.T. knife switches
2 - Milliammeters, 0.50 ma
1 - Microammeter, 0-750 ua
1 - 1-1/2-volt battery
1 - 6-volt battery
(or transistor power supply)

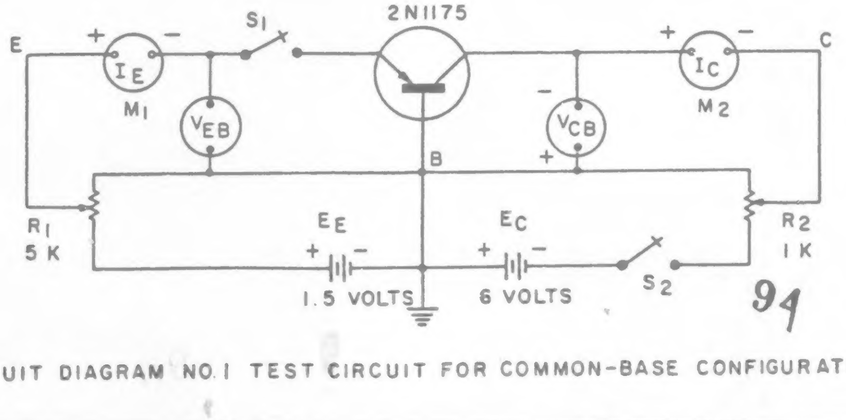
* The small variation between I_E and I_C can be detected only with accurately calibrated milliammeters.

Procedure for Object A:

Before proceeding with this experiment consult your transistor manual and determine the manufacturer's ratings for maximum collector current (I_C) and maximum collector power dissipation.

$$P_C = I_C \quad V_{CB} \quad \text{or} \quad I_C \ (\text{max.}) = \frac{P_C}{V_{CB}}$$

Calculate the maximum permissible current for each setting of V_{CB} shown in Observation Table 1 and record the results just below the bottom line. Do not exceed these maximums when taking data. The same maximum values must be considered when taking data for Observation Table 2.



CIRCUIT DIAGRAM NO.1 TEST CIRCUIT FOR COMMON-BASE CONFIGURATION

1. Connect the test circuit as given in Circuit Diagram No. 1, switches S_1 and S_2 open.
2. Set R_2 in the approximate middle of its range and adjust R_1 to make V_{EB} zero.
3. Energize the circuit and adjust R_1 until low values of emitter current and collector current are noted on meters M_1 and M_2.
4. Adjust R_1 for zero V_{EB}. This removes forward bias from emitter-to-base circuit and sets the emitter-to-base circuit at cutoff. M_1 should read zero current.
5. With V_{EB} at zero, adjust R_2 for zero V_{CB}. The voltmeter should read zero. Observe the collector current and record in Observation Table 1 for emitter current of zero and a collector voltage of zero.

OBSERVATION TABLE 1

V_{CB} Versus I_C - Common Base Connection

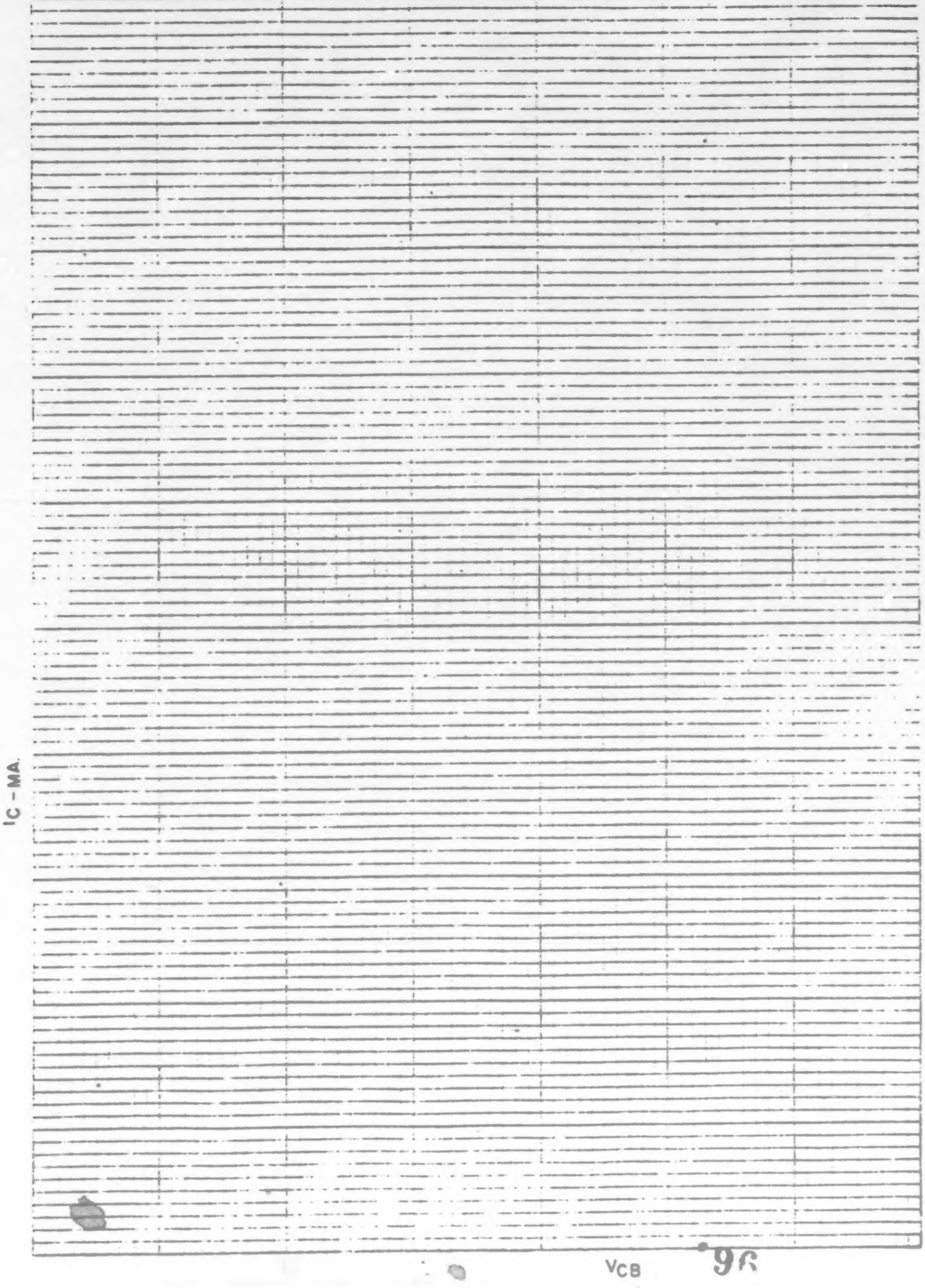
I_E, MA	I_c, MA											
	COLLECTOR VOLTS, V_{CB}											
	0	-0.5	-1	-1.5	-2	-2.5	-3	-3.5	-4	-4.5	-5	-5.5
0												
1												
2												
4												
6												
8												
10												
15												
20												

6. With I_E at zero, adjust R_2 to every value of V_{CB} shown in Table 1. Observe and record the value of collector current for each value of V_{CB}.
7. Again, adjust R_2 for a zero value of V_{CB} and set R_1 for an I_E reading of 1 milliampere in the emitter circuit.
8. Observe and record the collector current for each value of V_{CB} in Table 1.

   CAUTION: Be sure I_E remains at 1 milliampere.

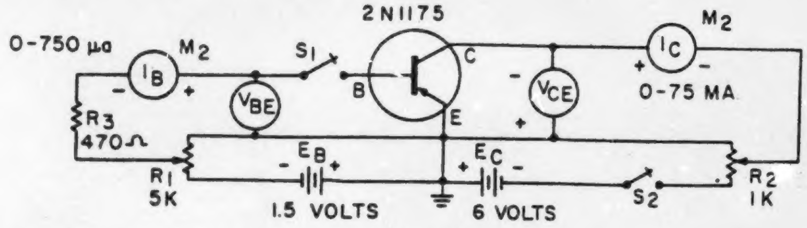
9. Repeat this process and record the results in Table 1 for emitter current values of 2, 4, 6, 8, 10, 15 and 20 milliamperes.
10. De-energize circuit and plot the family of characteristic curves from the data in Observation Table 1.

GRAPH Plot the family of characteristic curves for the 2N1175 transistor using the observation data in Table 1. Use the collector current in milliamperes as the ordinate axis and the collector volts as the abscissa axis.



Procedure for Object B

11. Reconnect the Type 2N1175 transistor for the common-emitter circuit given in Circuit Diagram No. 2



CIRCUIT DIAGRAM NO. 2 TEST CIRCUIT FOR COMMON-EMITTER CONFIGURATION

12. Energize circuit and adjust R_1 until there are low values of I_B indicated by M_1 and collector current indicated by M_2.
13. Adjust R_1 to zero position. Now the base current should be zero.
14. Adjust R_2 to zero position. The voltmeter should read zero. Observe and record the value of collector current in Observation Table No. 2.
15. Adjust R_2 to every value of collector volts in Table 2 and record the collector current in millamperes.
16. Adjust R_1 for a base current of 50 microamperes. Again adjust R_2 for every value of collector volts in Table 2 and record the collector current in milliamperes.
17. Repeat this process for the base current values shown in Table 2.

OBSERVATION TABLE 2 V_{CE} Versus I_C = Common-Emitter Connection

I_B, μA	I_C, MA											
	COLLECTOR VOLTS, V_{CE}											
	0	0.5	-1	-1.5	-2	-2.5	-3	-3.5	-4	-4.5	-5	-5.5
0												
50												
100												
150												
200												
250												
300												
350												
400												
450												
500												
550												
600												

GRAPH Plot the family of characteristic curves for the 2N1175 transistor using the observation data in Table 2. Use the collector current in milliamperes as the ordinate axis and the collector volts as the abscissa axis.

Questions:

1. Compute the value of alpha from the family of curves, using Observation Table 1. Select values in the vicinity of I_C equals 4 milliamperes and V_{CB} equals -3 volts. Show all work.

2. In the common emitter circuit as the base current varies with a constant V_{CE}, how does I_C vary? Explain.

3. In a common emitter circuit using an NPN transistor, how would the I_C vary with respect to I_B?

4. Using the value of alpha obtained in Question 1, calculate beta from
$$\beta = \frac{\alpha}{1-\alpha}$$

5. Alpha refers to the current gain in a common base circuit, while beta refers to the current gain in a common emitter circuit. Which circuit has the greater current gain? Briefly explain why.

The transistor used in this experiment must be used in Experiments 18 and 19.

Additional Reference:

Lurch, E. Norman - Fundamentals of Electronics